Agricultural Biotechnology in Developing Countries: Towards Optimizing the Benefits for the Poor

Edited by
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AGRICULTURAL BIOTECHNOLOGY IN DEVELOPING COUNTRIES

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PREFACE

This publication is based on invited papers presented at the conference "Agricultural Biotechnology in Developing Countries: Towards Optimizing the Benefits for the Poor", held in November 1999 at the Center for Development Research (ZEF), University of Bonn. The conference was convened in collaboration with the International Service for the Acquisition of Agri-biotech Applications (ISAAA), Hoechst Schering AgrEvo GmbH (now Aventis CropScience) and the German Foundation for International Development (Deutsche Stiftung für internationale Entwicklung – DSE). The financial and organizational support by all co-organizers is gratefully acknowledged.

The event grew out of ZEF's research project on the economics of biotechnology, which is being sponsored by the German Research Council (Deutsche Forschungsgemeinschaft – DFG) and the German Agency for Technical Cooperation (Deutsche Gesellschaft für Technische Zusammenarbeit – GTZ). Empirical studies within this research project were carried out in close cooperation with ISAAA. Both organizations felt that the time was ripe to overcome the emotional polemics of the current debate about agricultural biotechnology by organizing an international and interdisciplinary forum on biotechnology strategies that can benefit the poor. Experts and interested persons from over 30 different countries participated in the conference, including economists, political and social scientists, molecular biologists, plant breeders, development practitioners and private-sector business people as well as representatives from governmental and non-governmental organizations. The paper presenters were selected for their extensive knowledge and experience with the individual topics covered.

For the purpose of this publication, the individual papers as well as the design of the volume were peer reviewed. The authors revised their manuscripts accordingly and also took into account comments received during the conference. The book examines a wide – but not all encompassing – range of issues associated with agricultural biotechnology. A fairly young and very dynamic discipline, most of modern biotechnology's big potentials for the developing world have yet to materialize. Rather than providing conclusive facts about the outcome of these potentials, this book offers a state-of-the-art analysis of the field and highlights the institutional and policy weaknesses that need to be overcome to optimize the technology's benefits for the poor. A lively and constructive discussion – free of prejudices – among all stakeholders is a precondition for making progress in this important subject, and we hope that this book helps to move this conversation forward.

Of course, the publication would not have been possible without the substantial endeavors of many individuals. We appreciate the assistance of Hans Jochen de Haas, Karl Heinz Wolpers, Peter Jugelt and Eva Scholz-Tonga in preparing the conference program. We would also like to thank all the contributors for their efforts to prepare and revise the papers. For technical assistance in processing and editing the text we are particularly grateful to Kerstin Becker, David Alvarez and Max Holtmann.

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Chapter 1

INTRODUCTION

Matin Qaim, Anatole F. Krattiger, and Joachim von Braun

1 BACKGROUND

In the past, the fundamental forces that improved the world's food supply were the interactions of economic, institutional and technological change and innovation. In the early twenty-first century, however, hunger and poverty still remain persistent phenomena in large parts of the world. Today, around 800 million people suffer from chronic food insecurity; almost all of them reside in developing countries (FAO, 1999a). Although the relative proportion of the undernourished shrank significantly over the last 30 years, the absolute number of hungry people has decreased only slightly. In some parts of the world – notably in Africa – the number has actually increased. Rapid demographic and economic developments further aggravate the situation. The medium-variant projections of the United Nations forecast a population growth of almost one-third until the year 2020 (UN, 1999). During the same period, the average per capita incomes in developing countries will more than double (Pinstrup-Andersen et al., 1999). Consequently, the global demand for food will increase tremendously both in terms of quantity and quality.

Food security is a complex function of many different supply- and demand-side related factors, and no single instrument can solve all the hunger and malnutrition problems. Yet, against the background of limited land and water resources, it is clear that sustainable food security will require the continued utilization of technology for enhancing the resource productivity of food production. Crop productivity at the global level is still increasing; nonetheless, growth in farmers' yields has been slowing since the 1980s, and in some parts of the world the yields of major food crops have even tended to level off (cf. FAO, 1999b; Anderson, 1994). Biotechnology could help reverse this alarming trend.

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In European countries with populations that enjoy high-incomes, agricultural biotechnology is much contested. This is also increasingly the case in North America, partly because consumers are concerned about foodsafety and biodiversity risks. Especially with respect to genetically modified crops, fears have been raised about new risks for human health and the environment. Human knowledge is limited, and so the existence of unknown risks cannot be ruled out with absolute certainty – for transgenic crops or any other technology. But according to current scientific research, there are no indications that genetically modified crops are more dangerous than varieties bred traditionally. Scientific arguments notwithstanding, many people in richer countries feel uneasy about transgenics and prefer a zealously cautious approach. After all, at high income levels, the need for new agricultural technologies providing for low-cost production of nutritious food is often not fully acknowledged. From the perspectives of small farmers and poor consumers in low-income countries, however, the situation looks very different. With its special focus on the poor in the developing world, this volume assesses the international implications of modern crop biotechnology. This task requires a multidisciplinary approach, one that considers economic, social, institutional and policy issues alongside aspects of the natural sciences.

2 BIOTECHNOLOGY: CONDITIONS AND CONSTRAINTS IN DEVELOPING COUNTRIES

Biotechnology covers a wide range of different techniques that can be used for very diverse purposes. In this publication we confine the discussion to the application of modern biotechnology in crop production and crop improvement, including such tools as cell and tissue culture, marker-assisted selection, functional genomics and genetic engineering.

Recent advances in molecular biology have made it possible to develop crops that are resistant to major biotic and abiotic stress factors. Plants with modified quality characteristics, which could boost the productivity in food production and processing while promoting ecologically sound agricultural practices, are also beginning to appear (cf. Abelson and Hines, 1999). The potentials are particularly bright for developing countries, where the need for new farm technologies is most pronounced (Persley and Lantin, 2000; Wambugu, 1999; Krattiger, 1998). In recent years, the global area commercially cultivated with transgenic crops has increased exponentially (James, 1999), but most of this area lies in the industrialized countries. Furthermore, although a few developing countries already grow substantial areas with transgenic crops, most low- and middle-income economies are still far away from using modern biotechnology on a large scale. A more widespread deployment of biotechnology in developing countries is not just desirable from a food security perspective – it is a *sine qua non* for an equitable international technology evolution.

There are manifold reasons why most of the developing countries are lagging so severely behind many industrialized countries in biotechnology. Important factors include the following:

- *High startup costs.* Modern biotechnology research and development (R&D) is resource intensive in terms of human and financial capital, and many developing countries are overstrained and unable to develop desirable technologies completely on their own.
- *Institutional and policy constraints.* Apart from human and financial capital constraints, there are often institutional impediments in developing countries that limit the commercial exploitation of biotechnology. Regulatory capacities in biosafety, foodsafety and intellectual property rights (IPRs) management are usually underdeveloped, and efficient linkages between upstream and downstream research are missing. Moreover, policy support at the national level is often inadequate for maximizing the benefits of the new technology and minimizing its possible negative externalities.
- *Complex and fragmented markets for innovation.* The lion's share of biotechnology R&D expenditures in industrialized countries is made by private, transnational companies: approximately 80 percent of the relevant resources are spent by the corporate sector. But private companies are hesitant to focus their research on the needs of developing countries because of the economic risk associated with insufficient institutional mechanisms and market infrastructures. These countries in general, and the potential clients in the small farm sector in particular, also lack purchasing power, which makes it more difficult to attract investments.
- *Weaknesses in national and international public research.* Most centers of the Consultative Group on International Agricultural Research (CGIAR), whose mandate is to serve as a bridge between the advanced science and technology available in industrialized countries and the specific needs of the world's poor, have been rather slow to recognize the full potential of biotechnology. Indeed, the organization of international research and many national agricultural research systems (NARSs) (particularly in regard to IPR policies) are unable to effectively respond to the changing conditions.

One must also mention the international public debate about biotechnology. Spurred by antagonistic interest groups, this debate is primarily focused on environmental, health and social risks. There is no doubt that this debate is influencing policy decisions in developing countries, too. With little empirical evidence on the benefit side, policy-makers are understandably hesitant about what to do (Qaim and von Braun, 1998). A wait-and-see-strategy is dangerous, however, because of the risk that biotechnology will bypass the developing world, thus increasing technological and economic inequalities between North and South.

3 OBJECTIVES AND STRUCTURE OF THE BOOK

Political and institutional adjustments at national and international levels are needed to provide the poor with better access to biotechnology and to enable the technology to contribute to sustainable food security and poverty alleviation. This book attempts to address these issues from a policy and a research perspective. In particular it addresses the following questions:

- What are the potentials, risks and prospects of biotechnology in developing-country regions?
- What are the main economic and institutional constraints that might hinder an equitable biotechnology evolution, and what needs to be done to overcome these constraints?
- In what particular areas can more policy-oriented research improve the knowledge base for related decisions?

The book is subdivided into five interrelated parts, each consisting of various chapters. A comprehensive overview of the individual topics is given at the beginning of each part, but very briefly here are some of the issues discussed. Part I ("The General Framework") analyzes the international status and future prospects of agricultural biotechnology in terms of both research and application, including biosafety aspects. The commercial exploitation of modern biotechnology has increased exponentially in the last few years. Yet it is stressed that biotechnology is not a substitute for traditional techniques of crop improvement but an extension of them that must be efficiently integrated into existing innovation systems.

Part II ("Regional Outlook") gives an up-to-date description of biotechnology developments and needs in Latin America, Africa and Asia. The chapters describe the scope of biotechnology R&D in these regions, dissemination capacity and the challenges that must be overcome to ensure that poor farmers benefit from agricultural biotechnology. Although some interesting project examples are reported, biotechnology R&D and regulatory capacity in most developing countries is still rather weak because of underinvestment, skewed priorities and a lack of efficient international cooperation.

In Part III ("Expected Impacts"), a series of diverse viewpoints on the possible outcomes of biotechnology in developing countries is given. The potential biotechnology benefits for food producers and consumers are scrutinized, an important aspect of the public debate about biotechnology that has usually been ignored. Different institutional issues in biotechnology product delivery are also discussed. Concrete evidence about these issues is scant, so the information presented is largely based on case studies and ex ante simulations. Timely analysis is important, however, because – learning from shortcomings in the past – data need to be provided when they can still influence decisions. Economic research has an important role to play in bridging the gap between the large amount of information required for appropriate biotechnology policies and the small amount of information presently available.

Part IV ("Intellectual Property Rights") deals with various aspects of IPRs in the international biotechnology industry. Developing countries' access to biotechnology will depend to a great deal on international research partnerships and transboundary technology transfers, for which efficient IPR regulations are a necessary precondition. Focusing on implications for the poor, the chapters discuss the challenges posed by the international proliferation of proprietary claims and the increasing privatization of agricultural research. There is no one-size-fits-all solution that will improve the participation of developing countries in the biotechnology revolution, but some suggestions and examples for more effective international collaborations are offered.

Part V ("The Role of Different Players") analyzes the role of some of the important national and international actors (private companies, NARSs, CGIAR Centers and donor agencies) in providing access to biotechnology for the poor. The changing conditions of international agricultural research require a careful reconsideration of the traditional tasks of all relevant organizations. In particular, options for strengthening public-private sector R&D cooperation are examined. Such innovative partnerships should be based on a shared vision, comparative advantages, mutual trust and good communication systems. The last chapter of the book synthesizes the main findings of the individual parts and discusses related policy and research implications.

REFERENCES

Abelson, P.H., and P.J. Hines (1999): The Plant Revolution. *Science* 285, pp. 367-368.

Anderson, J.R. (ed.) (1994): *Agricultural Technology: Policy Issues for the International Community*. CAB International, Wallingford, UK.

FAO (1999a): *The State of Food Insecurity in the World 1999*. Food and Agriculture Organization of the United Nations, Rome.

FAO (1999b): FAOSTAT Online Database; Production Statistics. Food and Agriculture Organization of the United Nations, Rome.

James, C. (1999): Global Review of Commercialized Transgenic Crops: 1999. ISAAA Briefs, No. 12, International Service for the Acquisition of Agri-biotech Applications, Ithaca NY.

Krattiger, A.F. (1998): The Importance of Ag-biotech to Global Prosperity. ISAAA Briefs, No. 6, International Service for the Acquisition of Agri-biotech Applications, Ithaca NY.

Persley, G.J., and M.M. Lantin (eds.) (2000): *Agricultural Biotechnology and the Poor*. Consultative Group on International Agricultural Research, Washington, D.C.

Pinstrup-Andersen, P., R. Pandya-Lorch, and M.W. Rosegrant (1999): World Food Prospects: Critical Issues for the Early Twenty-First Century. Food Policy Report, 2020 Vision, International Food Policy Research Institute, Washington, D.C.

Qaim, M., and J. von Braun (1998): Crop Biotechnology in Developing Countries: A Conceptual Framework for Ex Ante Economic Analyses. ZEF Discussion Papers on Development Policy, No. 3, Center for Development Research, Bonn.

UN (1999): *World Population Prospects: The 1998 Revision*. United Nations, New York.

Wambugu, F. (1999): Why Africa Needs Agricultural Biotech. *Nature* 400, pp. 15-16.

PART I

THE GENERAL FRAMEWORK

OVERVIEW

Emil Q. Javier

In conventional breeding, researchers generate variation within species (and occasionally between sexually compatible species) and select new and better phenotypes by relying principally on numbers and a good eye. In early 1950s, the elucidation of the chemical structure of DNA raised hopes that more effective breeding techniques based on this knowledge would soon be available. In addition, advances in chemistry, physics, physiology, and genetics were making it possible to deliberately transfer genes from any living organism to target crops, livestock and even human beings. After 50 years of intensive, feverish scientific research, this new knowledge has been converted into novel products, such as improved breeds of crops and livestock, productivity- and quality-improving chemicals, drugs and other pharmaceutical products, as well as procedures which improve human health and living conditions.

Initially, nearly all the research was freely accessible in the public domain. As the commercial opportunities became apparent, however, the private agribusiness and pharmaceutical sectors began to invest heavily in biotechnology-related research and development (R&D). The pace of scientific discovery and technological innovation accelerated very rapidly, and today we are seeing the first wave of commercial products distributed at large scale. Since 1995, the agricultural area worldwide devoted to novel, genetically modified plants (also called transgenics) has increased to almost 40 million hectares, valued at about US $3 billion.

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But these novel biotechnological products have yet to receive universal acceptance. Fears have been raised about their potential to accidentally create super-weeds, super-pests, super-pathogens, and threaten biodiversity. Alarms have also been raised about how these “alien” genes and organisms may unwittingly introduce allergens and other anti-nutrition components into the food chain. Some see these new technologies as an attempt by big multinational corporations to further dominate agriculture in both developed and developing countries. Others see these genetic techniques as unnatural and reprehensible because they believe we are literally playing God with nature.

As the title of this book suggests, many of us in the international agricultural scientific community want to ensure that the benefits of modern agricultural biotechnology accrue not only to rich nations and rich agricultural producers but also to poor farmers and consumers in the developing world. We seek to conserve our common heritage: our environment and genetic diversity. We aim to guarantee that the food we produce is safe, pleasing and nutritious. We conceive of these problems as scientific challenges that we must address through universally accepted scientific protocols and regulations that we impose on ourselves.

As has historically been the case over a wide scientific and technological front, the private sector’s massive investments in agricultural R&D will lead to rapid progress. But the private sector will also naturally focus on those problems and products where the potentials for recovering its research investments are high. What do we do then to make sure that somebody looks after the technological needs of the so-called orphan markets, orphan commodities and the orphan traits?

This book’s first part provides the background and general framework for the more specialized topics that follow. The hectareage, value, and general outlook of transgenic crops at the global level are analyzed in the paper by *Clive James*. The global area of transgenic crops has expanded from 1.7 million hectares in 1996 to 39.9 million in 1999. Global sales of transgenic crops grew from US $85 million in 1995 to $2.3 billion in 1998 and to about $3.0 billion in 1999. James also presents interesting breakdowns of the global transgenic market by country, crop and trait. With few exceptions, the lion’s share of transgenic crops is grown in developed countries, involving species and traits that are important mostly to commercial agricultural growers. Biotechnological products of exclusive interest to developing countries have yet to get to market.

James also briefly introduces a number of issues that are the subjects of other papers in this book. For example, while the unprecedented adoption rates of the first generation of transgenic crops reflect growers’ strong endorsement of these products, the benefits to consumers are less obvious. It is likely that popular support for transgenics will broaden as new products in the R&D pipeline, with traits such as enhanced food quality and nutritional value, are delivered. Furthermore, issues of industry consolidation in agricultural biotechnology and the growing pressure to label transgenic products in Europe and America are tackled, and so are the implications of agricultural biotechnology for global food security. The demand for more food production is greatest in developing countries, but technology generation is largely in the domain of the private sector in the North. The needs of the poor in developing countries will not be served by the market-driven R&D efforts of private corporations in the North, and so the new technologies and the means to generate them should be in the hands of the developing countries. Without such a transfer of technology, the vision of a food-secure world in the future will dim.

For those who are less familiar with the scientific basis of this broad field of technological applications, *Christian Jung* provides a brief but encompassing overview of the new molecular techniques as they apply to plant breeding. He reviews the mechanics of how desirable "alien" genes are transferred and expressed from microorganisms, animals and other plants to target crops. He also explains how these techniques are applied as precise time- and labor-saving adjuncts to conventional plant breeding. Less appreciated and receiving less flak from biotech detractors are the uses of molecular tools for genetic mapping and the employment of genetic markers to make plant breeding and selection more effective and less costly. Plant selection based on outward appearance (i.e., the phenotype) is time-consuming, expensive and sometimes unreliable. With genetic markers, preliminary selection of the desirable plants can be done in the laboratory quickly and relatively cheaply. And lest anyone forgets, Jung reminds us that there is as yet no substitute to the traditional methods of plant breeding – of selection and field-testing.

The third and last paper of this part by *André de Kathen* gives a comprehensive overview of the international biosafety discussion in the light of the Cartagena-Protocol, which was adopted in early 2000 under the Convention on Biological Diversity. In addition to hopes, the new dimensions that biotechnology offers create fears in the public. Both real and imagined environmental and health risks – frequently intermingled with social and ethical concerns – are often in the fore of the debate. De Kathen discusses different concepts of risk and risk assessment and calls for clear and transparent decision-making processes. Risk management procedures have to find an appropriate balance between technological protection and promotion. Furthermore, biosafety initiatives in developing countries are reviewed and important shortcomings pointed out. The establishment of a sound biosafety system in a country requires more than technical guidelines.

Political commitment, public participation, human capacity and a clear allotment of responsibilities within a suitable institutional framework are all required. The Cartagena-Protocol can help to create and recreate awareness about biosafety issues, but without the action required at national levels there is the risk that the Protocol will hamper agricultural trade and technology transfer to the detriment of the poor in developing countries.

Chapter 2

TRANSGENIC CROPS WORLDWIDE: CURRENT SITUATION AND FUTURE OUTLOOK

Clive James

Abstract: In this paper, the global adoption of commercialized transgenic crops from 1996 to 1999 is reviewed, and the most recent period (1998-99) is characterized in detail. The global distribution of transgenic crops is described and a global database analyzing transgenic crops in 1998 and 1999 by country, crop and trait is presented. Estimates of the value of the global transgenic crop market during the period 1995 to 1999 are provided. In addition to these data on the current global status of commercialized transgenic crops, a brief commentary is provided on several issues, including the future outlook for transgenics, consolidation in the agri-biotech industry, the principal issues related to transgenic crops and their potential role for global food security.

1 INTRODUCTION

An annual review of the adoption and global distribution of commercialized transgenic crops has been provided by the *ISAAA Briefs*, a publication series of the International Service for the Acquisition of Agri-biotech Applications (ISAAA) (James, 1997, 1998, 1999a). The data provided show that between 1996 and 1999, twelve countries (8 industrial and 4 developing) contributed to more than a twenty-fold (23.5) increase in the global area of transgenic crops (see Table 1). These unprecedented adoption rates are the highest for any new technology in the agricultural industry. They reflect growers' satisfaction with products that offer such valuable benefits as more convenient and flexible crop management, higher productivity or net returns per hectare and a safer environment through reduced pesticide use. Taken together, these benefits also contribute to more sustainable agricultural practices.

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Table 1: Global area of transgenic crops (1996-99)

Year	Millions of hectares	Millions of acres
1996	1.7	4.3
1997	11.0	27.5
1998	27.8	69.5
1999	39.9	98.6

Source: James (1999a).

This paper reviews the distribution of the global transgenic crop area by country, by crop species and by the underlying modified crop trait for the 1998-99 period. Furthermore, a brief commentary is provided on several issues, including the future outlook for transgenics, consolidation in the agricultural biotechnology industry, the principal issues related to transgenic crops and their potential role for global food security.

2 GLOBAL DISTRIBUTION OF TRANSGENIC CROPS

The global area of transgenic crops increased from 27.8 million hectares in 1998 to 39.9 million hectares in 1999, an increase of 12.1 million hectares or 44 percent. In 1999, twelve countries grew seven transgenic crops commercially, and three of these countries grew transgenic crops for the first time (Portugal, Rumania and Ukraine).

2.1 Distribution by Country

In 1999, the proportion of transgenic crops grown in industrial countries was 82 percent, less than in 1998 (84%) (see Table 2). The remaining 18 percent were grown by developing countries, with most of that area in Argentina, and the balance in China, South Africa, and Mexico.

Listed in descending order, the transgenic crop areas of countries in 1999 are: USA, 28.7 million hectares (72 percent of the global area); Argentina, 6.7 million hectares (17 percent of the global area); Canada, 4.0 million hectares (10%); China, approximately 0.3 million hectares (1%); and Australia and South Africa, which each grew 0.1 million hectares of transgenic crops in 1999. The balance was grown in Mexico, Spain, France, Portugal, Rumania and Ukraine, each with less than 0.1 million hectares (see Table 3).

Table 2: Global area of transgenic crops in 1998 and 1999, by industrial and developing countries

	1998		1999		
	Millions of hectares	Percent	Millions of hectares	Percent	Increase (Ratio)
Industrial countries	23.4	84	32.8	82	9.4 (0.4)
Developing countries	4.4	16	7.1	18	2.7 (0.6)
Total	27.8	100	39.9	100	12.1 (0.4)

Source: James (1999a).

As in 1998, the largest increase in the farming of transgenic crops in 1999 occurred in the USA (8.2 million hectares, a 0.4 fold increase), followed by Argentina (2.4 million hectares, a 0.6 fold increase), and Canada (1.2 million hectares, a 0.4 fold increase). The USA continued to be the principal grower of transgenic crops in 1999, although its share of the global area was slightly lower (72%) in 1999 than in 1998 (74%). China's transgenic crop area increase was the largest relative change, increasing 3.0 fold from less than 0.1 million hectares of *Bacillus thuringiensis* (*Bt*) cotton in 1998 to approximately 0.3 million hectares in 1999, which is equivalent to 1 percent of the global share. Argentina's share of the global transgenic crop area

Table 3: Global area of transgenic crops in 1998 and 1999, by country

	1998		1999		
	Millions of hectares	Percent	Millions of hectares	Percent	Increase (Ratio)
USA	20.5	74	28.7	72	8.2 (0.4)
Argentina	4.3	15	6.7	17	2.4 (0.6)
Canada	2.8	10	4.0	10	1.2 (0.4)
China	<0.1	<1	0.3	1	0.2 (3.0)
Australia	0.1	1	0.1	<1	<0.1 (—)
South Africa	<0.1	<1	0.1	<1	<0.1 (—)
Mexico	<0.1	<1	<0.1	<1	<0.1 (—)
Spain	<0.1	<1	<0.1	<1	<0.1 (—)
France	<0.1	<1	<0.1	<1	<0.1 (—)
Portugal	0.0	0	<0.1	<1	<0.1 (—)
Rumania	0.0	0	<0.1	<1	<0.1 (—)
Ukraine	0.0	0	<0.1	<1	<0.1 (—)
Total	27.8	100	39.9	100	12.1 (0.4)

Source: James (1999a).

increased from 15 percent in 1998 to 17 percent in 1999. Canada's share remained the same at 10 percent.

2.2 Distribution by Crop

In descending order of area, the seven transgenic crops grown in 1999 were soybean, maize, cotton, canola, potato, squash, and papaya (see Table 4). Transgenic soybean and maize continued to be ranked first and second in 1999, accounting for 54 and 28 percent of the global transgenic crop area, respectively. Cotton (3.7 million hectares) and canola (3.4 million hectares) shared the third position in 1999, each occupying approximately 9 percent of the global area. Potato, squash, and papaya occupied less than 1 percent of the global area of transgenic crops in 1999.

2.3 Distribution by Trait

The relative rankings of the principal transgenic crop traits were the same in 1998 and 1999 (see Table 5). Herbicide tolerance remains the highest by far, at 71 percent in both 1998 and 1999. Insect-resistant crops decreased from 28 percent in 1998 to 22 percent in 1999. But stacked genes for insect resistance and herbicide tolerance increased significantly in both maize and cotton in the USA, from 1 percent in 1998 (0.3 million hectares) to 7 percent in 1999 (2.9 million hectares), an 8.7 fold increase. Virus resistance traits in potatoes, squash, and papaya occupied less than 1 percent and less than 0.1 million hectares in both 1998 and 1999.

Table 4: Global area of transgenic crops in 1998 and 1999, by crop

	1998		1999		
	Millions of hectares	Percent	Millions of hectares	Percent	Increase (Ratio)
Soybean	14.5	52	21.6	54	7.1 (0.5)
Maize	8.3	30	11.1	28	2.8 (0.3)
Cotton	2.5	9	3.7	9	1.2 (0.5)
Canola	2.4	9	3.4	9	1.0 (0.4)
Potato	<0.1	<1	<0.1	<1	<0.1 (—)
Squash	0.0	0	<0.1	<1	— (—)
Papaya	0.0	0	<0.1	<1	— (—)
Total	27.8	100	39.9	100	12.1 (0.4)

Source: James (1999a).

Table 5: Global area of transgenic crops in 1998 and 1999, by trait

	1998		1999		
	Millions of hectares	Percent	Millions of hectares	Percent	Increase (Ratio)
Herbicide tolerance	19.8	71	28.1	71	8.3 (0.4)
Insect resistance (*Bt*)	7.7	28	8.9	22	1.2 (0.2)
Bt/herbicide tolerance	0.3	1	2.9	7	2.6 (8.7)
Virus resist./other	<0.1	<1	<0.1	<1	<0.1 (—)
Total	27.8	100	39.9	100	12.1 (0.4)

Source: James (1999a).

3 MAJOR CHANGES IN 1999

Between 1998 and 1999, the major changes in the area and global share of transgenic crops were the following:

- The global area of transgenic crops increased from 27.8 million hectares in 1998 to 39.9 million hectares in 1999, an increase of 12.1 million hectares (44%). Seven transgenic crops were grown commercially in twelve countries in 1999, three of which, Portugal, Rumania and Ukraine, grew transgenic crops for the first time.
- The four principal countries that grew the most transgenic crops in 1999 were USA, 28.7 million hectares (72 percent of the global area); Argentina, 6.7 million hectares (17%); Canada, 4.0 million hectares (10%); and China, 0.3 million hectares (1%). The balance was grown in Australia, South Africa, Mexico, Spain, France, Portugal, Rumania and Ukraine.
- In industrial countries, the increase in the area used to grow transgenic crops between 1998 and 1999 remained significant, expanding 3.5 times faster than in developing countries (9.4 million hectares versus 2.7 million hectares).
- Soybean contributed most (59%) to the global growth of transgenic crops, with an increase of 7.1 million hectares between 1998 and 1999. This is followed by maize at 23 percent (2.8 million hectares), cotton at 10 percent (1.2 million hectares), and canola at 8 percent (1.0 million hectares).

Table 6: Dominant transgenic crops at the global level in 1999

Crop	Millions of hectares	Percent of total
Herbicide-tolerant soybean	21.6	54
Bt maize	7.5	19
Herbicide-tolerant canola	3.5	9
Bt/herbicide-tolerant maize	2.1	5
Herbicide-tolerant cotton	1.6	4
Herbicide-tolerant maize	1.5	4
Bt cotton	1.3	3
Bt/herbicide-tolerant cotton	0.8	2
Total	39.9	100

Source: James (1999a).

- There were three noteworthy developments in terms of traits: herbicide tolerance contributed the most (69 percent or 8.3 million hectares) to global growth between 1998 and 1999; the stacked genes of insect resistance and herbicide tolerance in both maize and cotton contributed 21 percent (2.6 million hectares); and insect resistance increased by 1.2 million hectares in 1999 (10%).
- Of the 4 major transgenic crops grown in 12 countries in 1999, the two principal crops of soybean and maize represented 54 and 28 percent, respectively, for a total of 82 percent of the global transgenic area. The remaining 18 percent was shared equally between cotton (9%) and canola (9%).
- In 1999, herbicide-tolerant soybean was the most dominant transgenic crop, grown on 54 percent of the global transgenic area as compared to 52 percent in 1998 (see Table 6). It was followed by insect-resistant maize (19 percent compared to 24 percent in 1998), herbicide-tolerant canola (9%), *Bt*/herbicide-tolerant maize (5%), herbicide-tolerant cotton (4%), herbicide-tolerant maize (4%), *Bt* cotton (3%), and *Bt*/herbicide-tolerant cotton (2%).

Between 1998 and 1999, the four major factors that influenced the changes in the absolute area of transgenic crops and in the relative global share of different countries, crops and traits were:

- the substantial increase of 4.8 million hectares in herbicide-tolerant soybean in the USA (from 10.2 million hectares in 1998 to 15.0 million hectares in 1999, equivalent to 50 percent of the 30.0 million hectare US soybean crop in 1999), coupled with an increase of 2.1 million hectares in herbicide-tolerant soybean in Argentina (from 4.3 million hectares in 1998 to an estimated 6.4 million hectares in 1999, equivalent to approximately 90 percent of the 7.0 million hectare Argentinean soybean crop in 1999);

- the significant increase of 2.2 million hectares of transgenic maize (insect resistant, *Bt*/herbicide tolerant, and herbicide tolerant) in the USA from 8.1 million hectares in 1998 to 10.3 million hectares in 1998, equivalent to 33 percent of the 31.4 million hectare US maize crop in 1999;
- the increase of 1.0 million hectares of herbicide-tolerant canola in Canada from 2.4 million hectares in 1998 to 3.4 million hectares in 1999, equivalent to 62 percent of the 5.5 million hectare Canadian canola crop in 1999; and
- the increase of 1.0 million hectares of transgenic cotton in the USA, from 2.2 million hectares in 1998 to 3.2 million hectares in 1999 (equivalent to 55 percent of the 5.9 million hectare US cotton crop in 1999). The 3.2 million hectares of transgenic cotton in 1999 comprised 1.5 million hectares of herbicide-tolerant cotton. The balance of 1.7 million hectares was equally divided between *Bt* cotton and cotton with the stacked genes of *Bt*/herbicide tolerance.

The combined effect of the above four factors resulted in a global area of transgenic crops in 1999 that was 12.1 million hectares higher and 1.4 fold (44%) greater than in 1998. This is a significant year-on-year increase considering the high percentage of the principal crops planted with transgenics in 1998. Commercialized transgenic crops were grown for the second year in two countries of the European Union (30,000 hectares of *Bt* maize in Spain and 1,000 hectares of *Bt* maize in France). In addition, Portugal grew more than 1,000 hectares of *Bt* maize for the first time in 1999. Two countries in Eastern Europe grew transgenic crops for the first time in 1999: Rumania grew introductory areas of herbicide-tolerant soybean (more than 1,000 hectares) and planted less than 1,000 hectares of *Bt* potatoes, and Ukraine grew *Bt* potatoes (less than 1,000 hectares). There may also have been a small area of *Bt* maize grown in Germany in 1999 but this could not be verified and so is not included in the global database.

4 VALUE OF THE GLOBAL MARKET AND CONSOLIDATION IN THE BIOTECH INDUSTRY

The value of the transgenic crop market is based on the sales price of transgenic seed plus any technology fees that apply. Unlike the estimates published in the Preview of *ISAAA Briefs* 12 in October 1999 (James, 1999a), the most recently revised estimates from Wood Mackenzie (personal communication) exclude non-genetically modified herbicide tolerant seed. Global sales of transgenic seed have grown rapidly from 1995 onwards. Initial global sales of transgenic seed were estimated at US $ 1 million in 1995. Sales increased in value to $ 152 million in 1996, and increased by approximately 450 percent in 1997 to reach $ 851 million. Sales increased by another 130 percent between 1997 and 1998 to reach $ 1.95 billion in 1998. For 1999, the author projects the value of the transgenic seed market at US $ 2.7-3.0 billion, when again the largest increase was in the USA, followed by Argentina, Canada and China on a country basis. Earlier projections had indicated that the global market for transgenic crops would reach approximately US $ 3 billion in 2000, $ 8 billion in 2005 and $ 25 billion in 2010.

Biotechnology-driven consolidations in the form of acquisitions, mergers and alliances have been a dominant feature of the biotechnology industry. In the three year period 1996 to 1998 alone, corporations commercializing transgenic crops and involved with seeds, agricultural chemicals, and the life sciences were engaged in more than 25 major acquisitions and alliances valued at US $17 billion (James, 1998). Several implications arise from the consolidation of biotechnology interests in the private sector, including the following:

- Fewer corporations have a larger market share of the transgenic crop business.
- The scale of research and development (R&D) investment in biotechnology by an individual corporation has increased substantially to US $1 billion or more per annum. This is significant considering that R&D investments have to be sustained over a 10 year period to complete product development and registration.
- With the globalization of agriculture, the strategy for deploying transgenic crops has become international in scope and coincides with the implementation of the world trade protocol.
- The onus for the effective and equitable deployment of transgenic crops that can make essential contributions to global food security now rests by and large with government and the private sector. On the one hand, the private sector must continue to exercise its comparative advantage in product development and distribution at equitable prices. On the other hand, governments must ensure that products are marketed equitably and competitively, in accordance with responsible regulations that are based on objective assessments, completed within reasonable time frames to meet national priorities, and optimized to the maximum extent possible through international harmonization.

The pace of biotechnology-driven consolidations in industry was slower in 1999 than in the previous three years. There were, however, some significant activities in 1999. DuPont opted to increase its 20 percent (US $1.7 billion) equity position in Pioneer to 100 percent for an additional $7.7 billion. Furthermore, most of the large multinationals with investments in seeds, crop biotechnology and crop protection reviewed their investments and initiated restructuring. This has resulted in more focus and the downsizing of programs, which in turn is leading to new alliances and mergers. Late in 1999, Novartis and Zeneca merged their agricultural operations, and at year-end Monsanto and Pharmacia announced a merger of equals in a US $23.4 billion deal.

The study of genomes, known as genomics, involves the mapping, sequencing, and analysis of genomes to determine the structure and function of every gene in an organism. Genomic information can be used to improve useful plant traits through genetic engineering. During the period 1997 to 1999, all of the leading companies made significant investments in plant genomics, a field pivotal to the industry's growth that is catalyzing a new generation of alliances, acquisitions, and mergers.

5 PRINCIPAL ISSUES RELATED TO TRANSGENIC CROPS

Issues related to transgenic crops range from the various ethical objections of consumers to concerns about the biosafety, in particular the possible environmental effects of the unintended genetic drift of transgenes from transgenic crops to conventional crops or wild relatives. The food safety of transgenic crop products is also an issue, particularly the use of antibiotic markers and the possibility of allergens in products derived from transgenic crops. The dominant issues in the European Union remain the public acceptance of transgenic crops and the labeling of products derived from them. There is a growing understanding that informed consumer choice of food is an important principle that should be respected. Whenever possible, consumers should have the choice to purchase products derived from conventional or transgenic crops. Market demand for conventional food products in Europe has contributed to policy changes for grain handlers, food processors, and retailing companies, all of which must now segregate and identify commodities from transgenic and conventional crops. In some cases, premiums are being offered for conventional crop commodities, and this two-tiered pricing system could have significant implications for transgenic crops. Given current uncertainties, however, it is premature to predict the potential impact this might have on the adoption of transgenic crops in the near term. The role of the private sector, particularly the dominance of multinationals and the proprietary nature of the technology, is also an issue for some interest groups. Finally, the role and potential contribution of transgenic crops to global food security is a subject of continuing discussion.

6 OUTLOOK FOR THE FUTURE

The number of countries growing transgenic crops has increased from 1 in 1992, to 6 in 1996, to 9 in 1998, and to 12 in 1999. The exceptionally high adoption rates of the first generation of transgenic crops reflect the multiple benefits to growers. The first generation of transgenic crops has already demonstrated that incorporating input traits can control biotic stresses, something not possible with conventional technology. For example, effective, targeted control of specific cotton and maize insect pests as well as papaya and potato virus diseases have been developed. In fact, the R&D pipeline of transgenic crops is full of new and novel products that will be commercialized in the next five years. These will offer a rich mix of at least 20 new input traits and an equal number of output traits that will improve both the quantity and quality of food. Of course, transgenic crops are not a panacea. Biotechnology has limitations just like any other technology, and it must be managed responsibly in conjunction with other technologies. Nonetheless, a multiple-thrust strategy that capitalizes on the full potential of both conventional crop improvement and transgenic crops would offer a unique opportunity to utilize technology alongside other essential inputs – including improved distribution and population control – to ensure global food security. Approaches based on single inputs will fail; instead, we must employ creative strategies with multiple thrusts that address the major issues.

7 GLOBAL FOOD SECURITY

Global population reached 6 billion on 12 October 1999 and it will reach 8 billion by 2025 and 9 billion by 2050 (UN, 1999). Feeding a global population that will increase 50 percent over the next 50 years is one of the most formidable challenges facing mankind. It is a challenge made even more difficult because nearly all the increase of 3 billion people in the next 50 years will be in developing countries (60 percent of it will be in Asia, where half of the world's 1.3 billion poor people reside).

Poverty and hunger are inextricably linked. Resource-poor farmers, their families, and the landless make up 70 percent of the world's poor. They live in rural areas and suffer the most from low crop yields. Improved technology can increase crop productivity and circumvent distribution constraints by allowing farmers to grow more food in the locations where it is most needed. This will reduce the suffering, disease, and death caused by chronic malnutrition. Currently, 24,000 people a day die from hunger and hunger-related causes – three-quarters of them are children. 90 percent of these deaths are due to chronic malnutrition and only 10 percent due to wars and acute famine. Fortunately, over the last 20 years new technology and other improvements have almost halved hunger deaths from 41,000 per day in 1980 to 24,000 today. The adoption of higher yielding transgenic crops that produce more nutritious food and feed products can further decrease this number.

In the early 1990s, many were skeptical of transgenic crops and the impact they could make on production in the near term at the farm level. There was even more skepticism about the appropriateness of transgenic crops for developing countries, particularly their ability to meet the urgent food, feed and fiber needs of resource-poor farmers. But much to the chagrin of opponents, transgenic crops are succeeding in both industrial and developing countries. In 1999, transgenic crops occupied 40 million hectares globally. They were grown by 8 industrial countries and 4 developing countries, including China, where 1.3 million small farmers benefit significantly from *Bt* cotton. Indeed, contrary to popular belief, the cutting-edge technology of transgenic crops is appropriate to small farmers. The genes are incorporated in the most universal, most trusted technology known to every subsistence farmer in the world – the seed.

The unprecedented, high adoption rates of transgenic crops in both industrial and developing countries from 1996 to 1999 reflect their significant and multiple benefits to growers. Transgenic crops are increasing productivity, decreasing pesticide use and making possible more convenient management practices, all of which are lowering production costs and creating more sustainable farming systems.

But by far the most compelling case for plant biotechnology is its potential to significantly contribute to the future food security and alleviation of abject poverty and hunger in developing countries, where over 800 million people suffer from malnutrition today (McCalla, 1999). And the benefits of biotechnology for the world's poor will continue to grow. The next generation of transgenic crops will provide more nutritious food with remedies for such nutritional problems as vitamin A deficiency, which afflicts 400 million people in developing countries.

Yet, although the use of biotechnology in medicine has been accepted by the global community as a means to provide better health care, there is a growing global debate about transgenic crops, despite the fact that they can make an equally important and critical contribution to the fight against malnutrition and hunger. The nucleus of this debate is in Europe, where in the last year the situation has regressed. Several countries are implementing moratoria on the commercialization of transgenic crops. Anti-biotechnology organizations are staffing and organizing vigorous global campaigns to spread European concerns to North America and to developing countries in Southeast Asia, Africa, and Latin America. Their well-resourced and aggressive campaigns have vandalized transgenic crop field trials, and they are attacking the scientific and regulation efforts of governments and of the biotechnology and food industries. They seek to erode the public's acceptance of biotechnology and to eliminate transgenic crops and their products from the global market place. Ironically, this will deny others the right to choose between transgenic and non-transgenic crops, which was one of the initial goals of the anti-biotechnology groups. In contrast to the unified front of the anti-biotechnology groups, the global science and development community has not organized an effective response to inform the world of the facts about transgenic crops so that well-informed decisions can be made. The failure to take urgent action in implementing such an initiative could result in the global erosion of confidence in transgenic crops. Those who stand to lose the most if this occurs are the poor in developing countries.

The recent Nuffield Council on Bioethics Report from the United Kingdom stressed the moral imperative and obligation of industrialized countries to share transgenic crops with those developing countries who want to deploy them to fight against hunger and poverty (Nuffield Council on Bioethics, 1999). Transgenic crops are proprietary and developed almost exclusively by the private sector in industrial countries, and most of the global transgenic crop area to-date is in the North. But while the source of this technology is in the North, the greatest need in terms of food security is in the South. Biotechnology transfer programs can play a vital role in building national capacity in biotechnology and in establishing regulations that will allow for the safe and responsible testing and adoption of transgenic crops, and we must work harder to develop these kinds of collaborative projects. The magnitude of the challenge of feeding tomorrow's world is difficult to conceive and is probably best captured by the following statement: "In the next fifty years mankind will consume twice as much food as mankind has consumed since the beginning of agriculture 10,000 years ago."

The benefits of agricultural biotechnology are not being lost on developing countries. Four of them have already commercialized transgenic crops, and China was the first country to introduce a commercialized transgenic crop in the early 1990s. Argentina is a global leader in the accelerated adoption of transgenic crops, and Mexico and South Africa have already commercialized transgenic crops. Given that over 800 million people suffer from malnutrition today in the Third World, and that the food gap of many developing countries is expected to more than double in the next 25 years, the important potential contribution of transgenic crops for developing countries is evident (James, 1999b).

REFERENCES

James, C. (1999a): Global Review of Commercialized Transgenic Crops: 1999. ISAAA Briefs, No 12, Preview, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

James, C. (1999b): Achievements of Plant Breeding and its Contribution to Global Food Security. Proceedings of The World Seed Conference, Cambridge, UK.

James, C. (1998): Global Review of Commercialized Transgenic Crops: 1998. ISAAA Briefs, No. 8, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

James, C. (1997): Global Status of Transgenic Crops in 1997. ISAAA Briefs, No. 5, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

McCalla, A.F. (1999): World Agriculture Directions: What Do They Mean For Food Security? Paper presented at Cornell University, 30 March 1999, Ithaca, NY.

Nuffield Council on Bioethics (1999): *Genetically Modified Crops; Ethical and Social Issues*. Nuffield Council on Bioethics, London.

UN (1999): *World Population Prospects: The 1998 Revision.* United Nations, New York.

Wood Mackenzie (2000): Personal Communication. Edinburgh, Scotland.

Chapter 3

MOLECULAR TOOLS FOR PLANT BREEDING

Christian Jung

Abstract: Molecular techniques will have an enormous impact on plant breeding. Marker-assisted selection and marker-based genetic distance analysis are presently used for many breeding programs. They help to accelerate backcrossing procedures and to predict the performance of progeny. Furthermore, genetic engineering tools offer interesting alternatives for crop production. In particular, they can facilitate the development of plants with better pest and disease resistance and improved quality characteristics. Such transgenic plants have undergone extensive safety studies and were commercially grown on 40 million hectares worldwide in 1999. Nevertheless, breeding in the laboratory alone will never be a realistic alternative, and so future plant breeding will continue to rely on traditional procedures of selection and field-testing. Locally adapted varieties will be fundamental whether transgenic technologies are employed or not.

1 INTRODUCTION

Raising the yield potential of crops so that we can feed the world's growing population will be a major task for the future. Gene technology has recently gained greater significance for both selection and broadening genetic variation. Indeed, there is no doubt that the genetic improvement of crops will become more and more important. In public discussions, however, both the benefits and risks of this technology are largely overestimated. To help spread the facts, the following provides a short overview of the main principles of molecular breeding. In brief, the breeding process can be divided into two phases. First, genetic variation is created by crosses between distantly related lines. Second, improved elite genotypes are identified after replicated cycles of selection. The entire process is not short: to release a new variety can take as long as 14 years.

M. Qaim et al. (eds.),
Agricultural Biotechnology in Developing Countries: Towards Optimizing the Benefits for the Poor, 25–37.

2 MOLECULAR GENOME ANALYSIS

Genes are the smallest unit of genetic information in all organisms. Genetic information in higher plants is encoded by a macromolecule called deoxyribonucleic acid (DNA). DNA is composed of sub-units called nucleotides which are characterized by four different bases, two of which pair to form double stranded DNA. The size of a DNA molecule can be measured in base pairs (bp).

Most of the DNA is located in the nucleus of a plant cell, however, small DNA molecules are also present in plastids and mitochondria. The total genetic information of a cell is called the genome. The nuclear genome of crop plants ranges from 500 x 10^6 to 16.000 x 10^6 bp. The genome is subdivided into smaller units called chromosomes. Each chromosome contains one DNA molecule. The number of chromosomes is characteristic for a given species.

Molecular genome analysis aims to determine the structure and function of genomes and genes. Due to the huge amount of DNA present in a plant cell, powerful techniques for genome analysis have been developed in the past 15 years. As a first step, genetic landmarks are localized all around the genome. The landmarks are small stretches of DNA usually between 100 and 2000 bp. They are molecular markers used to genetically map the genome (Paterson et al., 1991). Today, the genomes of all major crop species are enriched with molecular marker loci. As a second step, those markers located in close vicinity of agronomically important genes are identified.

Molecular marker analysis can proceed in the following manner. It starts with DNA isolation, preferably from leaves. In the case of RFLPs (restriction fragment length polymorphisms), DNA is cleaved with enzymes (restriction endonucleases) and subsequently separated on agarose or polyacrylamide gels. During gel electrophoresis, large fragments are separated from smaller ones. Then DNA is blotted onto a nylon filter (Southern transfer) and probed with a short DNA molecule which is either radioactively labeled or labeled with a fluorescent dye. As a result, homologous restriction fragments will bind to the probe which can be visualized on an autoradiogram. The size of the band unambiguously identifies the allele at a given marker locus. By means of genetic recombination analysis, linkage to a locus with agricultural importance is determined.

Modern marker technologies amplify small amounts of DNA via polymerase chain reaction (PCR). Amplified fragments are then separated by gel electrophoresis and visualized by staining with a DNA specific dye. Corresponding to RFLPs, the size of the amplified fragment indicates on the marker allele. PCR-based markers are much more powerful because they can be combined with high throughput techniques that allow for the determination of many loci at a time.

Dense genetic maps based on molecular markers are available for all major crop species. In most cases, agronomically important genes have been included, such as disease resistances or quality traits. However, most yielding component traits are encoded not by one single gene but by the interaction of many genes (quantitative inheritance). The corresponding loci (quantitative trait loci, QTL) can be mapped with molecular markers.

The first plant genome to be completely sequenced will be *Arabidopsis thaliana*, which has the smallest genome among all plants with approximately 130 Mb (Somerville and Somerville, 1999). Six research groups in Japan, Europe and the United States are collaborating on the sequencing project. About 92 percent of the genome sequence is currently available in public databases, and a large proportion of the genes are also represented by partial DNA sequences. It is anticipated that the complete genome sequence of *Arabidopsis* will be available by the end of 2000. Among agriculturally important plants, rice will be the first to be sequenced. Rice has a relatively small genome and is a staple food in many countries of the world. It contains about 3.5 times as much DNA as *Arabidopsis* but only about 20 percent as much DNA as maize and only 3 percent as much DNA as wheat. Under the leadership of Japan, a worldwide consortium from USA, France, Thailand and South Korea is sequencing the rice genome. In spring 2000, however, Monsanto announced that they have already sequenced the rice genome in a private effort. Since the genome organization of cereals such as rice, wheat, maize, sorghum and millet is very highly conserved, many rice genes are expected to have homologous counterparts in other cereals.

Assigning functions to genes will be the next step in functional genome analysis. Through plant genome projects, genes of agricultural importance will be identified, offering the possibility of manipulating corresponding pathways and of altering the phenotype of crop plants through genetic engineering. Many such genes have been cloned. For example, a gene from *Arabidopsis* was cloned that after overexpression resulted in higher freezing tolerance (Jaglo-Ottosen et al., 1998). Other genes for salt tolerance (Apse et al., 1999) or disease resistance (Rossi et al., 1998) offer new approaches for future plant breeding.

3 MOLECULAR MARKERS IN PLANT BREEDING

3.1 Marker-Assisted Selection

Molecular markers assist in the selection process. There are numerous examples of how markers can be applied to select for characters that are controlled by only one gene, a Mendelian inheritance. If the corresponding phenotype is difficult to determine, as is the case with many disease resistances, marker-assisted selection can speed up the selection process. Markers have been applied to practical breeding to select for stress tolerance, restorer genes, self incompatibility, vernalization requirement and growth type, as well as for disease (virus, bacteria, fungi), insect and nematode resistance (see Table 1).

The marker phenotype can be determined through very small amounts of DNA even at the seedling stage, which enables an early selection of favorable genotypes. If the character is inherited in a dominant manner, markers can also be used to select homozygous individuals among segregating populations.

Otherwise, time-consuming testcrosses have to be made to distinguish homozygous from heterozygous individuals.

In backcross programs, a valuable gene is transferred from a donor line to an elite line (recipient). The offspring is backcrossed with the recipient line to select elite plants with the donor character, (e.g., disease resistance). This procedure takes several generations to select a backcross line with almost the same genetic constitution as the recipient. To accelerate this process, molecular markers can be employed in the first backcross generation to select individuals with a high proportion of elite alleles.

Most agriculturally important characters, such as yielding components, are quantitatively inherited. While numerous QTL have been identified in all major crop species, applying corresponding markers related to QTL has been disappointing. This is because many marker-QTL relationships are not stable among different genetic backgrounds. The general applicability, therefore, of marker assisted-selection for breeding is limited. A novel approach has been

Table 1: Ranking of applications of DNA markers for present utility in cultivar development programs

Application		Average ranking
1.	DNA fingerprinting parents for creating source populations	5.6
2.	DNA fingerpr. parents for predicting performance of progeny	6.9
3.	Back-crossing transgenes	3.2
4.	Transferring qualitative (monogenic) factors	3.7
5.	Transferring quantitative factors	6.7
6.	Genetic mapping of quantitative trait loci	4.7
7.	Genetic mapping of qualitative trait loci	3.6
8.	Map-based cloning	7.6
9.	Monitoring homozygosity in progeny	5.5
10.	Fingerprinting progeny in recurrent selection programs	8.0
11.	Other	0.0

Note: In the ranking systems, 1 implies the greatest utility relative to other items on the list.
Source: Lee (1995).

proposed and successfully demonstrated for tomato and rice (Tanksley and Nelson, 1996). QTL from wild species with inferior yielding performance have been identified and transferred to elite material. A QTL from *Oryza rufipogon*, a wild relative of rice, resulted in a 17 percent increase of yield in rice while a QTL from *Lycopersicon hirsutum* increased the yield of a tomato line by 48 percent. This marker-assisted breeding method is expected to contribute significantly to breeding progress in the future. However, its value is restricted to inbreeding species where pure lines are used for cultivation, such as wheat and barley.

3.2 Genetic Distance Analysis

Breeding lines can be allocated to gene pools by means of DNA fingerprinting. This technique relies on molecular markers that cover the whole genome with equal distances. DNA fingerprinting is used with parents to create source populations. Parents should be only distantly related to create broad genetic variation in the offspring of such crosses. For hybrid breeding, parents from different gene pools are used to realize the superior yielding capacity of hybrids due to heterosis effects. DNA fingerprinting of parents can be helpful for predicting the performance of progeny.

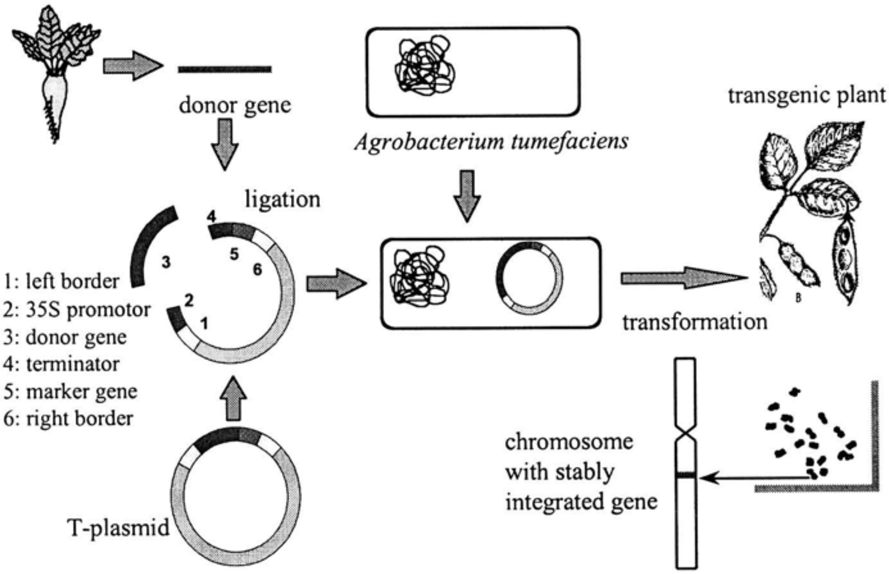
4 TRANSGENIC PLANTS

Despite the fact that marker techniques are frequently applied in plant breeding, their use in developing transgenic plants has attracted the most public attention by far. Listed below are some important techniques for producing transgenic plants that employ markers.

Agrobacterium-mediated gene transfer relies on *Agrobacterium tumefaciens* to transfer part of its genome into a plant cell's nucleus (see Figure 1). Genetically modified *Agrobacterium* vectors are routinely used to transform dicot species such as tomato, potato and rapeseed. Because they are non-hosts, monocot species – with the exception of rice – cannot be transformed in this way. In principle, the transgenic vector construct must contain a regulatory sequence called a promoter, a terminator, and the gene itself. However, most transgenic plants carry additional sequences that are used as selectable markers for antibiotic or herbicide resistances during plant regeneration.

In the past few years, plant transformation by microprojectile bombardment has become increasingly important. In principle, all plant species can be transformed in this manner. Tungsten or gold particles 1.2–1.7 μm in size

Figure 1: Agrobacterium tumefaciens mediated transfer



are accelerated by a particle accelerator under vacuum. The particles are coated with DNA, which is released into the cell during tissue passage. If the particles hit the nucleus, DNA can be stably incorporated into the genome. However, this is a rare event with a frequency of less than 10^{-8}. Furthermore, this technique must be used in conjunction with regenerable plant tissue (e.g., scutellum tissue from immature embryos or microspore-derived zygotic embryos). The particle gun technique has been successfully used to transform barley, millet, papaya, maize, wheat and rice (Becker et al., 1994; Vasil et al., 1993).

Plant protoplasts can be subjected to transformation in the presence of PEG and $CaCl_2$ or by electroporation, provided that they can be regenerated to whole plants. The stable integration of alien DNA into maize and rice has been accomplished using this method.

The latest development is the direct transformation of plastid DNA (plastom), which produces transplastomic plants. The DNA is integrated by a homologous recombination that relies on sequence homology between construct and plastid DNA. While this technique remains a challenge for crop species, it provides a major advantage because the high DNA copy number in the plastid results in high expression rates. Furthermore, because plastids are maternally transmitted via the egg cell, the transgenes of transplastomic plants will not be transmitted via pollen, an important environmental consideration.

After gene transfer, regenerated plants must be tested for stable expression and stable inheritance of the transgenes over the following generations. Preferably, only one copy should be integrated into the genome to facilitate later backcross breeding. Transgenic plants used in plant breeding can be classified according to their phenotype.

4.1 Herbicide Resistance

Herbicide-resistant plants were among the first transgenic plants to be created in the 1980s. The two major herbicides are glyphosate (Round up) and glufosinate (Liberty, BASTA). Glyphosate inactivates the enzyme 5-enolpyruvate-shikimate-3-phosphatesynthase (EPSPS), which is essential for the synthesis of aromatic amino acids in plastids. A glyphosate tolerance gene from bacteria has been transferred to higher plants and expressed under the control of a constitutive promoter. A targeting sequence directs the polypeptide into the plastid. Glyphosate-tolerant plants have been commercialized, and their usefulness for crop production has been proven mainly in maize, soybean and rapeseed.

Glufosinate (phosphinotricin) inactivates the enzyme glutaminesynthetase. This results in the accumulation of NH_4^+, which is toxic to the plant cell. A resistance gene encoding an N-acetyltransferase has been cloned from *Streptomyces* species and transferred to different crop plants. The gene product inactivates the herbicide by metabolizing phosphinotricin to acetylphosphinotricin. Phosphinotricin-resistant plants currently grown in the field include rapeseed and maize.

4.2 Disease and Insect Resistance

Although using transgenic technology for fungal and nematode resistance remains a challenge, it has successfully induced virus and insect resistance in different crop species (see Box 1). Molecular breeding for insect resistance, for example, has been very successful. By far the most important gene encodes for the δ-endotoxin of *Bacillus thuringiensis* (*Bt*), which is toxic to the larvae of many insect species. It binds to specific receptors in the larvae's gut, causing cell lysis and death. The δ-endotoxins are specific for the larvae of lepidopters, with no or low activity against other insects. Larvae feeding on transgenic plants that express *Bt*-genes die immediately. Today, more than 100 different δ-endotoxin genes are known, with

Box 1: Genetic engineering for disease and pest resistance

Virus resistance

- expression of viral coat proteins (coat protein-mediated resistance, CP-MR); expression of viral movement proteins; expression of viral satellite RNA; ribozymes; natural resistance genes

Insect resistance

- *Bt* toxin; protease inhibitors; alpha-amylase inhibitors; ribosome-inactivating proteins; lectins; natural resistance genes

Fungal resistance

- chitinases; glucanases; programmed cell death (RNase + pathogen-inducible promoter; phytoalexin genes (resveratrol); natural resistance genes

Bacterial resistance

- lysozyme; pectatlyase; natural resistance genes

Nematode resistance

- programmed cell death (suicide genes + feeding site-specific promoters); antibodies; natural resistance genes

polypeptides sharing between 20-90 percent of sequence homology. Grown large-scale throughout the world, insect-resistant varieties of tobacco, maize and cotton are significantly reducing the use of toxic insecticides. Recently, however, experimental data obtained in the USA about the monarch butterfly (*Danaus plexippus*) created concerns that *Bt*-plants may be causing damage to non-target organisms. But the relevance of these data for practical maize growing is doubtful because the data were obtained under artificial greenhouse conditions using leaves heavily powdered with pollen from *Bt*-maize.

The use of lectin genes for insect resistance has also been much discussed in recent months due to a study carried out in Scotland in which rats that were fed with potato spiked with lectins suffered from malfunctions of different organs. A committee of the British Royal Society regards the experiments non-scientific, although there is no doubt that lectins are harmful to mammalian species. No such transgenic plants have been commercialized or even tested in the field.

The use of α-amylase inhibitor genes has also been proposed for inducing insect resistance. The polypeptides interfere with the digestion of starch, which causes staggered growth in insect larvae feeding from transgenic plant material. No commercial products have been released so far.

Virus diseases often cause heavy crop production losses. Pesticides cannot control them, and so breeding varieties with coat protein-mediated resistance is urgent. The nucleic acid of a plant virus is coated by a protein. If the coat protein gene is transferred to plants, they will be resistant to further virus attacks. This technique has been extremely successful in different species such as potato, tobacco, sugar beet, and tomato. The resistance provides protection against the virus from which the gene was derived and against related viruses.

To obtain bacterial resistance, either antibiotic genes or natural resistance genes from plants have been employed. Recently, resistance against the pathogen *Xanthomonas oryzae*, a highly destructive pathogen in rice causing bacterial blight, was reported. The cloned *Xa21* gene was transformed to elite varieties, and transgenic lines with improved resistance have been selected. The improved lines did not exhibit undesirable traits often associated with conventionally bred lines (Tu et al., 1999).

4.3 Quality Improvement

The major storage components of plants, starch, proteins, and seed oils can be altered through genetic engineering (see Box 2). Starch is composed of amylose and amylopectin. When used as a raw material for industry, amylose-free starch is preferred. The gene for the enzyme GBSS (granule bound starch synthase), which is involved in amylose formation, can be inactivated by antisense transformation. Potato plants carrying the gene in the wrong orientation exhibit only small amounts of amylose, but their starch content is comparable to non-transgenic controls.

Genetic manipulation has been extremely successful in altering the fatty acid composition of seed oils. Since all genes involved in fatty acid metabolism have been cloned, corresponding pathways can be altered to either promote or prevent the synthesis of certain fatty acids. Furthermore, new genes have been introduced into crop plants, resulting in the synthesis of novel fatty acids that a given plant species lacks. For example, introducing a thioesterase from California bay into rapeseed results in the synthesis of lauric acid, a medium chain length fatty acid with 14 C atoms. In this way, rapeseed oil can be produced with a similar composition to that of palm oil.

Many storage proteins of staple foods like zein (maize) and patatin lack amino acids essential for human nutrition (isoleucine, leucine, methionine, phenylalanine, threonine, tryptophan, and valine). Site-directed mutagenesis has been applied to increase the lysine content of zein, but with low success due to changes in the tertiary structure of the proteins, which results in lower

Box 2: Genetic engineering for food quality

Fatty acid composition

Storage proteins

- lysine-rich storage proteins

Free amino acids

- feedback-insensitive DHDPS and AK enzymes

Micronutrients (Ca, Fe, J, Se)

- increased Fe-content: phytase, ferritin, metallothionine-like protein

Vitamins

- increase beta-carotene content (geranyl-geranyl-pyrophosphate)

Starch quality

- amylose-free potato

Food and food processing quality

- antisense inhibition of polyphenolic oxidases; trehalose; antioxidants: tocopherol, resveratrol; sweet proteins: thaumatine, modellin

Delayed fruit ripening

- antisense inhibition of polygalacturonase; blocking ethylene production

Improved feed quality

- phytase; cyanophycin

protein content. Alternative approaches are available (Falco et al., 1995). Normally, plant enzymes dihydrodipicolinic acid synthase (DHDPS) and aspartatekinase (AK), which are involved in lysine synthesis, are feedback-inactivated preventing the accumulation of lysine. Introducing genes for feedback-insensitive DHDPS and AK from *Corynebacterium* and *E. coli* into rapeseed and soybean led to a more than 100-fold increase of free lysine.

Plant foods provide almost all essential vitamins and minerals and a number of other health-promoting phytochemicals, but concentrations of micronutrients, such as Ca, Fe, J, Se, are often low in staple crops. Research is under way to understand and manipulate the synthesis of micronutrients so that crop nutritional quality can be improved. Genome sequencing projects are providing novel approaches for identifying plant biosynthetic genes of nutritional importance. The term "nutritional genomics" has been proposed to describe work at the intersection of plant biochemistry, genomics, and human nutrition (DellaPenna, 1999).

Recently, the improvement of Fe-content in rice was reported by introducing three different genes, a gene encoding a heat-tolerant phytase which breaks up phytic acid, a ferritin gene resulting in higher Fe-accumulation in the seeds, and a gene for a metallothionine-like protein improving Fe-absorption (Gura, 1999). In addition, the same transgenic rice contains a gene that increases the beta-carotene content. Beta-carotene is a precursor of vitamin A, and rice with higher vitamin A content would benefit more than 400 million people suffering from vitamin A deficiency, which causes a higher susceptibility to infections and blindness. The transgenic prototypes have been introduced into the breeding program of the International Rice Research Institute (IRRI) to produce varieties with superior nutritional value.

Delayed fruit ripening is essential for post-harvest storing and shipping of fruits. In tomato, genes coding for polygalacturonase have been inactivated by antisense technology. In that case, a gene construct in antisense orientation was introduced and stably expressed in plants. As a result, the mRNA of the native gene binds to the antisense mRNA, resulting in double stranded RNA that cannot be translated. The enzyme cannot be produced, and fruit tissue degradation is delayed. An alternative approach relies on blocking ethylene metabolism. Ethylene is essential to fruit ripening, and reducing its production produces the same effects as have been observed in tomato and melons using antisense technology (Ayub et al., 1996).

4.4 Others

For hybrid breeding of self pollinating species, male sterility is necessary to avoid selfing of the seed parent. Cytoplasmic male sterility (cms) is often found in natural populations and has been frequently used for breeding. In cereals, for example, if seeds are harvested, restorer genes are needed to restore male fertility and to enable seed set. However, there are plant species where male sterility and restorer systems are difficult to find (e.g., rapeseed, wheat). In this case, nuclear male sterility has been introduced by genetic modification (Mariani et al., 1992). An RNase gene was transformed into plants under the control of an anther-specific promoter, which inhibited pollen mother cells. Fertility was restored by crossing with another transgenic parent expressing an RNase inhibitor protein. In this way, male fertile hybrids have been obtained. This technology will facilitate hybrid breeding and increase the crops' yield potential in the future.

5 CONCLUSION

Molecular techniques will have an enormous impact on plant breeding. Marker assisted selection and marker-based genetic distance analysis are presently used for many breeding programs. Low-cost marker techniques have been developed that have been applied in developing countries to increase the efficiency of classical breeding programs. Transgenic plants offer interesting alternatives for crop production. In 1999, they were commercially grown on 40 million hectares worldwide and have been proven safe. Nevertheless, future plant breeding will also rely on traditional procedures of selection and field-testing. Breeding in the laboratory alone will never be a realistic alternative. Locally adapted varieties will be fundamental whether transgenic technologies are employed or not. Conserving and collecting germplasm must be a major task now and in the future.

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REFERENCES

Apse, M.P., G.S. Aharan, W.A. Snedden, and E. Blumwald (1999): Salt Tolerance Conferred by Overexpression of a Vacuolar Na^+/H^+ Antiport in Arabidopsis. *Science* 285, pp. 1256-1258.

Ayub, R., M. Guis, M. Benamor, L. Gillot, J.P. Roustan, A. Latche, M. Bouzayen, and J.C. Pech (1996): Expression of ACC Oxidase Antisense Gene Inhibits Ripening of Cantaloupe Melon Fruits. *Nature Biotechnology* 14, pp. 862-866.

Becker, D., R. Brettschneider, and H. Lörz (1994): Fertile Transgenic Wheat from Microprojectile Bombardment of Scutellar Tissue. *Plant Journal* 5, pp. 299-307.

DellaPenna, D. (1999): Nutritional Genomics: Manipulating Plant Micronutrients to Improve Human Health. *Science* 285, pp. 375-379.

Falco, S.C., T. Guida, M. Locke, J. Mauvais, C. Sanders, R.T. Ward, and P. Webber (1995): Transgenic Canola and Soybean Seeds with Increased Lysine. *Biotechnology* 13, pp. 577-582.

Gura, T. (1999): New Genes Boost Rice Nutrient. *Science* 285, pp. 994-995.

Jaglo-Ottosen, K.R., S.J. Gilmour, D.K. Zarka, O. Schabenberger, and M.F. Tomashow (1998): Arabidopsis CBF1 Overexpression Induces COR Genes and Enhances Freezing Tolerance. *Science* 280, pp. 104-106.

Lee, M. (1995): DNA Markers and Plant Breeding Programs. *Advances in Agronomy* 55, pp. 265-344.

Mariani, C., V. Gossele, M. De Beuckeleer, M. De Block, R.B. Goldberg, W. De Greef, and J. Leemans (1992): A Chimaeric Ribonuclease-Inhibitor Gene Restores Fertility to Male Sterile Plants. *Nature* 357, pp. 384-387.

Paterson, A.H., S. Tanksley, and M. Sorrells (1991): DNA Markers in Plant Improvement. *Advances in Agronomy* 46, pp. 39-90.

Rossi, M., F.L. Goggin, S.B. Milligan, I. Kaloshian, D.E. Ullman, and V.M. Williamson (1998): The Nematode Resistance Gene Mi of Tomato Confers Resistance Against the Potato Aphid. *Proceedings of the National Academy of Science USA* 95, pp. 9750-9754.

Somerville, C., and S.C. Somerville (1999): Plant Functional Genomics. *Science* 285, pp. 380-383.

Tanksley, S.D., and J.C. Nelson (1996): Advanced Backcross QTL Analysis: A Method for the Simultaneous Discovery and Transfer of Valuable QTLs from Unadapted Germplasm into Elite Breeding Lines. *Theoretical and Applied Genetics* 92, pp. 191-203.

Tu, J., I. Ona, T.W. Mew, O.S. Fluh, and S.R. Datta (1999): Transgenic Rice Variety IR72 with Xa21 is Resistant to Bacterial Blight. *Theoretical and Applied Genetics* 97, pp. 31-36.

Vasil, V., V. Srivastava, A.M. Castillo, M.E. Fromm, and I.K. Vasil (1993): Rapid Production of Transgenic Wheat Plants by Direct Bombardment of Cultured Immature Embryos. *Biotechnology* 11, pp. 1553-1558.

Chapter 4

MANAGING BIOSAFETY CAPACITY DEVELOPMENT: TECHNICAL AND POLITICAL ASPECTS

André de Kathen

Abstract: Biotechnology and genetic engineering are new tools with the potential to improve agricultural production, create new diagnostics and develop new medicinal applications. But modern biotechnology may not necessarily make everything better in all cases. Indeed, there are important biotechnology safety issues in health, the environment and sustainable development. Also, any debate on biosafety will fail if it does not consider the social, economic and political implications. On the other hand, any risk assessment will also fail if it does not specifically and differentially address potential areas of impact. Finally, successful biosafety capacity building in developing countries will require public and political commitment. This paper examines the current status of biosafety systems in developing countries and suggests a participatory strategy for developing national biosafety frameworks in the light of the Cartagena-Protocol.

1 INTRODUCTION

Biotechnology and information technology are expected to change our life dramatically. Both technologies overrun previous frontiers: bounds of nature on the one hand, distance and time on the other. The tools provided will not only improve production and processing but will change markets, generate new key players, explore new natural resources, and fuel "globalization" by establishing new links and modes of cooperation. The quite painful shift from agricultural to industrial societies in the North took almost a century; the shift to a knowledge-based society took a decade. Even if it appears that globalization will eliminate old economic blocks in the long run, for the moment, the speed of change itself is generating concern,

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especially for developing countries. A global map for the new technologies is being drawn up faster than most people are able to understand – let alone respond to – its implications. The pace of change is certainly faster than our understanding of its ethical and developmental implications (UNDP, 1999).

Just 18 years after the first genetically engineered plant was produced, transgenic crops today cover more than 40 million hectares worldwide. In the USA and Argentina, the area under transgenic crops has reached up to 10-15 percent of the cultivated area and more than 50 percent for a given crop (APHIS, 2000; FAO, 2000). Over 20,000 transgenic field trials with around 60 different crop species have been carried out in more than 40 countries (James, 1999; de Kathen, 1999). More than a dozen mammals, amphibia, fish and insects have been genetically engineered and released for testing purposes. These rapid technological developments have generated public concern. Fears have been expressed about the potential negative impacts of genetically modified organisms (GMOs) on the environment and human health. Some fear that GMOs or their products may contain new toxic and allergenic compounds, that they may become invasive weeds, or that the transmission of introduced DNA may "pollute" and harm biological diversity. So far, no serious harm has been reported from the release or consumption of GMOs, but biosafety issues remain dominant in the public biotechnology debate and are often intermingled with social, economic and ethical concerns.

This paper discusses biosafety issues with a special view to developing countries. The following two sections briefly describe the scenario within which the biosafety debate takes place today. I then review previous biosafety initiatives, specifically addressing bottlenecks and shortcomings. Section 4 comments on the public perception of risk, its consequences for risk assessment and the most-frequently cited concerns with respect to GMOs. Shaping and organizing a biosafety framework is the focus of the fifth section, which considers the need for public participation, precise and transparent procedures for risk assessment and the commitment needed at the national, political and public levels to develop human and institutional capacity. The last section then discusses the implications of the International Protocol on Biosafety, addressing the question of how the Protocol can be used to protect the natural, human and economic resources of developing countries.

2 THE INTERNATIONAL SCENARIO

2.1 The Cartagena-Protocol

The Agenda 21 and the legally binding Convention on Biological Diversity (CBD) adopted in 1992 call for the development and implementation of means to control and manage risks resulting from GMOs (Article 8g) and "alien" organisms (Article 8h). Since 1989, genetically modified crops have been released in Morocco, Belize, Chile, Dominican Republic, El Salvador, Bolivia and Zimbabwe without any specific regulations in place.[1] Due to poor border control and plant quarantine conditions, the lack of appropriate labeling and a limited capacity to detect and deal with genetically modified planting material, there are probably a large number of additional, undetected cases. At least for Argentina and Brazil, news reports indicate illegal or non-legal transboundary movement of transgenic soybean. The need for an internationally respected and agreed upon safety procedure is obvious.

After several years of negotiation, Article 19.3 of the CBD finally resulted in the International Protocol on Biosafety, which was adopted in Montreal in January 2000.[2] The Protocol applies to the "transboundary movement, transit, handling and use of all living modified organisms that may have adverse effects on the conservation and sustainable use of biological diversity, taking also into account risks to human health". Interestingly, the CBD provides definitions for "biotechnology", "biological diversity" and "biological resources", but fails to define "biosafety". Biosafety is not even explained in the International Protocol on Biosafety, although obviously it is restricted to the potential risks of GMOs. The Cartagena-Protocol is the first implementation document of the CBD, and much more work is needed to balance the protection and sustainable use of biological diversity. Compared to the potential impacts of "alien" species, deforestation, pollution, pesticide application and the development of transport infrastructure, GMOs are probably not on top of the list of harmful phenomena.

On the other hand, the 130 members of the World Trade Organization (WTO), who account for over 90 percent of global trade, are pushing hard for the liberalization of international trade, increased market access and

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[1] This information is based on a comprehensive cross-country survey (de Kathen, 1999). Data were considered valuable if provided by governmental institutions, the releasing company and/or at least two independent non-governmental sources.

[2] The Biosafety Protocol is available on the internet (www.biodiv.org). A more comprehensive discussion of the Protocol's implications is presented in section 6.

reduced trade barriers. Although committees do exist that specifically address the needs of the least-developed countries, the WTO is trade- and profit-oriented. Conflicts over protective measures, such as those negotiated under the CBD and formulated in the Cartagena-Protocol, will probably influence the shape and scope of national biosafety frameworks. Since the early 1990s, international development agencies realized the need to define the minimum requirements of regulatory biosafety frameworks and to set the poles for risk assessment and management. But until the fifth meeting of the Conference of Parties to the CBD, such awareness among policy-makers was quite limited. The final negotiation rounds and the Cartagena-Protocol itself have obviously changed the situation.

2.2 Current Status of Biosafety Capacity Building

Less than half of the parties to the CBD, about 50-60 countries worldwide, have developed biosafety systems. In most cases, existing systems have established GMO-specific technical guidelines and GMO-specific legislation. Only a few developing countries have adopted operational biosafety systems that regulate the release and commercialization of GMOs by a competent body with some legal authority (see Table 1).

For the vast majority of developing countries, biosafety is not an issue of prime importance. This is not surprising, since most countries have not yet handled or released GMOs. But even for those developing countries with biosafety systems in place, as Table 1 indicates, these must be differentiated. Nigeria and Egypt, for example, presented technical guidelines on biosafety very early (in 1994) – with almost the same number of pages as the German guidelines. The Nigerian and Egyptian guidelines, however, were poorly drafted, had minimal content and were to be implemented in an environment with limited political/public awareness and participation. Since Egypt now intends to commercialize GMOs, it intends to modify its guidelines. The same applies to South Africa and Mexico, which suggests that the development of biosafety regulations is often more adapted to the requirements of companies and scientists than to the requirements of the country. With respect to intention and capacity, one may broadly categorize developing countries into four groups:[3]

[3] This categorization is subjective and cannot be substantiated by definitions. However, indicators like policy development, governmental commitment, biotechnology market, operational biosafety committees and institutional frameworks are available for many countries. See, for instance, OECD (www.oecd.org/ehs/country.htm) or BINAS (www.binas.unido.org/binas/regs.php3).

Table 1: Level of implementation of an operational biosafety framework in selected developing countries (status: late 1999)

Country	Biosafety policy	Legislation (act/ decree)	Technical guidelines	GMO release/safety review	Number of trials [a]	GMO area (millions of hectares)
Argentina	None	Yes	Yes	Yes/Yes	>200	6.7
Bangladesh	None	Pending	Yes	No/No	0	0
Belize	None	None	None	Yes/No	4	<0.1
Brazil	None	Yes	Yes	Yes/Yes	>30	~0.1
China [b]	None	Yes	Yes	Yes/Yes	>70	~0.3
Cuba	None	Pending	Yes	Yes/Yes	>30	n.a.
Egypt	None	None	Yes	Yes/Yes	6	<0.1
Malaysia [c]	None	Pending	Yes	No/No	0	0
Morocco	None	Pending	Yes	Yes/No	1	n.a.
Mexico	None	Yes	Yes	Yes/Yes	>120	<0.1
Namibia	Yes	Pending	Yes	No/No	0	0
Nigeria	None	None	Yes	No/No	0	0
South Africa [d]	Pending	Pending	Yes	Yes/Yes	>90	0.1
Thailand	None	None [e]	Yes	Yes/Yes	>6	<0.1
Zimbabwe [f]	None	Yes	Yes	Yes/No	1	n.a.

a. The number includes open field trial releases without physical containment.
b. Exact information on field releases before 1997 is difficult to validate for China. It can be assumed, however, that GMOs have been released without specific risk assessment. Since 1997, GMO releases have to be approved by the Ministry of Agriculture.
c. James (1997) lists Malaysia as a releasing country. No confirmation was obtained in our survey however.
d. A review of GMO releases has been carried out by the South African Committee for Genetic Experimentation (SAGENE) on a voluntary basis. A GMO-Act was formulated in 1997, and SAGENE functions as an advisory committee until the Act comes into force.
e. The Thai legislation is considered a soft law since it is based on voluntary action. "None" may be a contradiction; however, enforcement is limited.
f. Transgenic cotton has been planted in Zimbabwe, although it was known that the development of a biosafety framework was in progress. The field was burnt before harvest.

1. No opportunity, capacity or market for biotechnology research and the marketing of biotech products in the foreseeable future. Limited awareness of potential impacts on biodiversity and socioeconomic structure (e.g., Angola, Belize, Nicaragua).
2. Interest but limited capacity and lack of market analysis. Biosafety is an issue, since it is a prerequisite for donor assistance (e.g., Algeria, Cameroon, Nigeria).
3. Modern biotechnology is applied (or is close to being applied) but biosafety awareness is limited. Biosafety is rather seen as a hampering factor in development (e.g., Egypt, India, Kenya, Syria).

4. Modern biotechnology is applied (or is close to being applied) and a sound understanding of biosafety is available (e.g., Costa Rica, Mexico, Namibia).

This categorization is flexible, and development assistance has the potential to change the perception of biotechnology and biosafety in a country. Now, after a decade of "Biosafety Capacity Building" in developing countries, what has been achieved? Is it a sign of successful implementation that Kenya needs almost two years to decide on a release application and, to some extent, outclasses the European Commission? Why did respective initiatives receive limited attention and what are the major bottlenecks faced? How can we improve future activities aimed at assisting the development of national human and institutional resources that are urgently needed to implement the Cartagena Protocol? These are questions that are implicitly addressed in the following section.

3 INTERNATIONAL AND REGIONAL BIOSAFETY INITIATIVES – SUCCESS OR FAILURE?

International activities supporting biosafety capacity building date back to early 1990s. The lack of respective regulations in developing countries raised concerns that they would either be excluded from biotechnology developments or become uncontrolled testing grounds; examples are available for both scenarios. In the beginning, a limited number of workshops convened by various organizations focused specifically on biotechnology management.[4] Biosafety was one issue considered in the agenda, since donor agencies found biosafety a prerequisite for development aid in the field of biotechnology. Consequently, technical guidelines were rapidly adopted, occasionally simply copied from elsewhere. Recommendations and concepts were largely based on vague technical guidelines developed by the Organization for Economic Cooperation and Development (OECD) or the Food and Agriculture Organization of the United Nations (FAO), and were to be implemented "by the overall regulatory system which governs the release of new products in the agricultural sector" (Persley et al. 1993).

[4] Prominent organizations active in biosafety capacity building include the Biotechnology Advisory Center of the Stockholm Environment Institute (SEI/BAC), the International Service for National Agricultural Research (ISNAR), the United Nations Industrial Development Organization (UNIDO), the Agricultural Biotechnology Support Project (ABSP), and the International Service for the Acquisition of Agri-biotech Applications (ISAAA).

The concepts of sustainability in development aid may not have infiltrated all areas of technical and scientific cooperation at that time. Only Virgin and Frederick (1996) published an early report on developing evaluation criteria for biosafety capacity building. Bringing together policy-makers, regulators and donors, they produced a comprehensive list of criteria useful for monitoring and analyzing the biosafety implementation process. Biosafety was understood as a continuous process with a focus on the process itself instead of simply counting the number of countries with ratified technical guidelines.

Following the final rounds of negotiations on the Cartagena-Protocol in 1999 and 2000, several countries – supported by the Global Environmental Facility (GEF) and the United Nations Environment Program (UNEP) – launched programs to establish, implement or modify national biosafety regulatory systems (e.g., Bolivia, Bulgaria, Cameroon, Kenya, Hungary, Malawi, Mauritania, Namibia, Pakistan, Poland, Russia, Tunisia, Uganda and Zambia). Countries in Western Asia and Northern Africa are in the process of planning a regional initiative (Morocco, Algeria, Tunisia, Lebanon, Palestine, Jordan, Syria and Turkey). Similar regional initiatives are possible for Central America and Southeast Africa.

Now that attention to biosafety is growing in many developing countries, what kind of lessons could be learned from previous failures and shortcomings? In retrospective, the following factors accounted for the limited success in establishing operational biosafety frameworks:

- Scientists are often the first to consider the need for a biosafety system, but they are usually reluctant to regulate themselves and often lack the necessary links to responsible political decision-makers.
- Time pressures forced the adoption of poorly adapted technical guidelines that lacked the political support and commitment necessary for their enforcement, or regulators formulated policies, decrees and laws without considering available institutional capacities and needs within the country.
- Biosafety systems were implemented in an environment unfamiliar with the transport and handling of toxic or radioactive waste, hazardous organisms or impact assessment in general, so that elementary know-how was missing.
- Agriculture and biodiversity, two fields considered most likely affected by modern biotechnology, receive insufficient attention within national policies, notwithstanding their importance for the economy of developing countries.
- Milestones or evaluation criteria have not been part of development strategies.

- Public awareness and participation do not exist, hampering the implementation process and perhaps causing substantial mistrust and opposition.

In many industrialized countries, modern biotechnology has been in development (initially in academic institutes but now increasingly in the private sector) for more than 25 years. Consequently, there has been an extensive political and public debate in these countries about the technology's potential implications. Developing countries, in contrast, often do not have the chance to decide about the technology in a broader context but about whether specific products should be released or imported. They have been forced to draft technical guidelines to handle GMOs, even though genetic engineering has not yet been carried out in these countries. Human and institutional capacities, political commitment and public participation are only marginal, and development is, therefore, far from "sustainable". Finally, the debate on biosafety and biotechnology in developing countries has been instrumentalized by interest groups from both the pro and contra sides, perpetuating entrenched arguments rather than fruitful discussions. It appears, however, that the number of those willing to communicate is growing. Company representatives admit that they have not developed many biotechnology products to mitigate global hunger, and environmentalists admit that it may be necessary to assess specific applications and products – instead of indicting the whole process as such. Participatory approaches require genuine communication to be successful, and the quality of the discussions about biotechnology will continue to impact the development of biosafety frameworks (van den Daele, 1998). One initial step might be to substantiate the common perceptions of risks related to the release and consumption of GMOs.

4 RISKS RELATED TO GMOs

4.1 The Perception of Risks

Since risk assessment is central to any biosafety system, its principles and strategies are a matter of much debate. This sub-section, therefore, will elaborate more on the basic understanding of terms and philosophies than on technical details. The term "risk" is defined as the multiplicative product between likelihood and magnitude of a specific unwanted effect, whereby "unwanted effect" is already an anthropocentric term. This definition implies that risk can be identified and quantified mathematically. But risk also has a subjective dimension, because it relates to what we feel, accept or fear.

Unfortunately, the concept of risk is burdened with negative associations and can be easily instrumentalized. Even the term "risk assessment" per se suggests that a risk exists and that the intention is to analyze and assess its impact. Words really count in this debate. Especially when the burden of proof is with the applicant of a technology product whose safety will need to be demonstrated. Any debate on assessment procedures, therefore, requires an agreement on what is perceived as a risk in principle. A few statements may outline the direction:

- A priori, no scenario results in a zero-risk situation. The fact that we ignore a certain risk or that we are used to it does not change the likelihood or the magnitude of the potential damage.
- Risk is commonly associated with "doing" or "modifying", that is, something dynamic. In turn, "not doing" anything, that is, the static reference situation, is often implicitly regarded as safe. This is an inappropriate assumption; risk assessment needs to consider realistic alternative scenarios.
- In the public, the concept of risk is often confused with probability. For example, a horizontal gene transfer as such is not a risk. It occurs with a certain probability and the mere fact that it occurs is an important scientific finding, describing a feature of any genetic material (transgenic or not).

A very important point should be noted here: those who favored a strong precautionary principle in the Cartagena-Protocol did so in order to remove the decision-process from an invisible scientific arena into a transparent public space. Yet the same transparency should be applicable *vice versa* (i.e., it should be crystal-clear on what basis decisions are made). For instance, the factual moratorium – by the EU-council of Ministers of Environment in June 1999 – on the commercialization of GMOs in Europe is not the result of a negative risk assessment but politically motivated.

Limited resources also require priority setting. Biosafety assessment procedures have not been applied to non-GMOs, but such organisms may pose risks to the environment and human health, too. The introduction of Johnsongrass and water hyacinth into the US; africanized bees into the Americas; ragweed, hogweed, weed-beet and sunflower into Europe; guava into Mauritius; the spread of small-pox and measles to the Americas by the Spanish Conquistadors; and the numerous pandemics of cholera, influenza and pests certainly changed human history. Today, Marburg or Ebola viruses are transported around the world, and there are numerous other pathogens disseminated by businessmen, tourists or even goods (e.g., cut flowers carrying fungi, insects and bacteria). Pathogen dispersal and disease outbreaks also gain momentum due to shrinking wildlife habitats and the high population densities of humans and domestic animals (Daszak et al., 2000). In fact, many of the risks of non-GMOs are identified, and the potential harm is almost quantified, but there is no feedback mechanism. It would be wrong to hypothesize that there is no risk associated with GMOs. But these illustrations should help to put the concept of risk assessment into a rational perspective.

4.2 Risks Related to GMOs in the Public Debate

This sub-section briefly discusses the most frequently cited risks associated with the release of GMOs into the environment or their consumption by humans.

Human Health Risks

Allergenicity of GMOs. Food allergies are commonly triggered by IgE-mediated reactions, afflicting about 1-2 percent of adults and 5-8 percent of infants. They are caused by proteins and peptides that are often quite stable to food processing and digestion. Peanuts, hazelnuts, soybean, wheat, eggs, milk, crabs/shrimps and fish account for almost 90 percent of the allergic reactions to foodstuffs. For several allergies, the responsible amino-acid sequence has been identified. This allows for rapid screening, provided that respective serum banks and databases exist – as they do in many industrialized countries (OECD, 1997; Taylor, 1996). It can be assumed, however, that the pattern of allergic reactions may differ according to the conditions of the consumer and the food product. Processing, mixing ingredients and new food compositions hamper any attempt to avoid allergenic compounds. Labeling ingredients – including GMOs – would improve the life of those suffering from hypersensitivity. Finally, allergies should be distinguished from food intolerances (see below).

Toxicity of GMOs. Food intolerances are more common than allergies. Often, causes have not been identified, but intolerances are usually triggered by small molecular weight compounds such as lactose or glutamate. The term "toxin", therefore, is used here in its broadest sense. Five scenarios leading to modified toxicity can be identified: (i) the introduced DNA (or the transcribed RNA) is toxic, (ii) the encoded protein is toxic, (iii) the metabolites produced by a new protein are toxic, (iv) the reaction mediated by the recombinant protein leads to a metabolic shift, (v) unknown metabolites may be produced which are toxic (pleiotropic effect). It is rather unlikely that the introduced DNA causes toxic effects since DNA and RNA are common and comparably uniform chemicals in all living organisms and foods. For proteins, known metabolites and metabolic shifts, respective analytical methods are available (feeding studies, deductive analysis, Ames-test) and so they do not represent a major concern. For the fifth scenario, however, no concept is available because the biochemical processes in any living organism are largely unknown. This is a weak point in the favored concept of "substantial equivalence" (Kok and Kuiper, 1996), in which equivalence is determined by the pattern of analyzed parameters. To address this shortcoming, the analysis of metabolite profiles has been suggested. But given the thousands of metabolites, it is rather unlikely that reliable and efficient analytical procedures can be developed for all metabolites. Current toxicity analyses of GMOs focus on known toxic compounds (e.g., solanine in potatoes). References and appropriate controls are considered necessary to justify statements about increased or decreased toxicity. In this respect, the assessment of GMOs might be even easier than the analysis of products resulting from mutations or "wide crosses" like nectarines (a mutant peach), tangelo (grapefruit/tangerine) or triticale (wheat/barley) (Miller, 1999). After all, it should be kept in mind that malnutrition and the limited access to high quality food are still major concerns in developing countries. In emerging economies (e.g., China and Eastern Europe), food intolerances triggered by substantial modifications of the daily diet may represent another one.

Antibiotic resistance. Antibiotic-resistance genes, often used as selectable markers in gene-transfer experiments, are a matter of concern because the massive release and consumption of antibiotic-resistant plants may reduce antibiotics' effectiveness. In fact, several antibiotics used in GMO-production are used in human and veterinary medicine. However, the most abundant selectable marker-gene, *npt-II*, conferring resistance to a spectrum of aminoglycoside-antibiotics such as neomycin and kanamycin, has undergone substantial testing. It was found harmless because respective antibiotics are rarely used as a drug, resistance to antibiotics is comparably common in soil microorganisms, uptake of the protein is low and interference with medication is not expected (Redenbaugh et al., 1994).

Environmental Risks

Besides these risks to human health, GMOs are expected to impact the environment, especially in regards to biodiversity. The concerns are as follows:

- increased weediness by introgression of herbicide-resistance genes to compatible "weedy" relatives (causing super-weeds) or the emergence of volunteers;
- loss of biodiversity by simplified cropping systems promoting genetic erosion;

- new pathogenic bacteria or viruses by horizontal gene transfer, conjugation and recombination;
- increased invasiveness by transmission of “fitness” genes (resistance to abiotic or biotic stresses);
- unexpected impact on non-target organisms, due to limited knowledge of the transgene or by unforeseeable pleiotropic effects;
- genetic pollution by genetic introgression since previously established “natural” genetic boundaries do not exist anymore.

Weediness and invasiveness. Despite the problems in determining weediness or invasiveness, a few scenarios should be discussed. First, there is the possibility of a transgenic crop escaping from an agricultural area and replacing wild species. There is no documented example, however, of a crop becoming a weed in unmanaged ecosystems. Second, the transgenic crop could “volunteer” and become invasive within the managed ecosystem – the agricultural area. But this was a problem even before the advent of genetic engineering and is often regarded as a purely agricultural problem (Torgersen, 1996). Third, the transgenic pollen might escape from the cultivated area and “contaminate” non-transgenic domesticated crops. In this case, there would be no increased weediness but serious economic and market issues are broached (e.g., if organic food is produced on the neighboring field). As a consequence, the Canadian National Farmers Union demands legislation that would compensate for unintended crop alteration (Hoyle, 1999). The Cartagena-Protocol has so far postponed a decision on liability and compensation (see below). Fourth, super-weeds may appear. Weedy relatives of domesticated crops can form a crop-weed complex through which herbicide-resistance genes are transmitted, potentially resulting in herbicide-resistant weeds or super-weeds (Darmency, 1994). However, herbicide resistance is not an outstanding “fitness” factor and can also be introduced by conventional breeding and selection. In addition, most available transgenic crops are resistant to a specific, non-selective herbicide. Acquiring resistance to a non-selective herbicide grants no immunity against any other (perhaps previously used) herbicide. The farmer will have lost one option to control a weed, an option he/she did not have before the GMO appeared. It should also be noted that introgression is not a character restricted to GMOs and that respective transgenes follow the same introgression pathways as do conventional organisms.

Impact on non-target organisms. Impacts on non-target organisms are likely to occur when the GMO is engineered for resistance against biotic stresses (e.g., insects). The *Bacillus thuringiensis* (*Bt*) toxin gene exists in many variants, each encoding for a certain protein (which is toxic to many lepidoptera larvae) with a more or less defined host range. Although *Bt*-

mixtures have been used as biological insecticides in organic farming for decades (accounting for about 1 percent of the insecticide market), host ranges have not been determined for all variants. In the US, numerous non-indigenous *Bt*-sprays have been approved. In fact, no impacts on non-target organisms have been reported, yet it appears that nobody has seriously looked for them. The same applies to hydrolytic enzymes for fungus resistance or lysozyme for bacterial resistance, both of which are characterized by a comparably broad host range. Legumes profit significantly from their symbiosis with nitrogen-fixing bacteria and (forest-tree) nurseries profit from mycorrhiza-fungi. It remains to be determined if and how broad host-range resistance genes might interfere with such symbioses. Assuming that the number of species – or potential non-target-organisms – is higher in countries rich in biodiversity, the probability of non-target effects is substantially higher than in countries comparatively poor in biodiversity.

Pleiotropic effects. Pleiotropic effects can be understood as expressed characters that are not directly related to the respective genotype. In other words, phenotypic modifications are observed but cannot be related to the modified genotype. The term is not restricted to genetic engineering and is well known from conventional breeding and classical genetics – even more so from mutation breeding. Introducing a transgene can result in pleiotropic effects. But because the function of the transgene is known, the chance of timely detection of pleiotropic effects is – at least in theory – higher than in conventional or mutation breeding.[5] The major difference from classical breeding is that transgenes usually find themselves in a new "genetic neighborhood", integrated somewhere in a genome where they usually do not belong. It is evident that the genetic background influences the magnitude and stability of gene expression. Furthermore, so-called position effects are quite frequently observed in primary transformants. GM crops used for food and engineered for increased tolerance against biotic stresses are especially the focus of risk assessment, because plant defense genes are known to bear the risk of being toxic or mutagenic to humans as well. Unexpected variations of expression levels of these introduced genes may, therefore, represent a serious risk. On the other hand, plants produce pesticides themselves, especially when damaged or attacked by plant pathogens. Ames et al. (1990) have analyzed 52 naturally occurring plant pesticides and found 27 to be cancerogenic. In other words, differences exist between GMOs and non-GMOs with respect to the cause of pleiotropic effects but potential consequences are comparable.

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[5] The International Atomic Energy Agency (IAEA) estimates that more than 1,500 crop varieties have been developed through irradiation. It is reasonable to assume that numerous pleiotropic effects occurred without having been analyzed carefully.

Horizontal gene transfer. Horizontal gene transfer is defined as the non-sexual transmission of DNA across species barriers. Conjugation between different bacteria is one example (albeit the definition of species with respect to bacteria is disputable). The identification of retroviral sequences in plants is another mode of DNA transmission. DNA transfer is also observed between kingdoms, for example, from bacteria to plants. Members of the genus *Agrobacterium* are quite famous for transmitting DNA into the plant genome. Trans-kingdom direct transfer of DNA, however, is probably a rare event and difficult to observe in an experimental setup. In fact, "no-one has been able to show that native bacteria will take up antibiotic resistance genes when exposed to transgenic plant material under natural conditions" (Syvanen, 1999). Moreover, it is not restricted to recombinant DNA (i.e., it is reasonable to assume that a transgene of transgenic maize is transferred with the same frequency as any other of the 50,000-100,000 maize genes). What is usually discussed in scientific publications and public debate is the probability of horizontal gene transfer, not necessarily its impact (see above).

5 INSTITUTING A BIOSAFETY FRAMEWORK

As a promising tool in sustainable development, biotechnology possesses technical components with implications in different dimensions. In addition to economic, social, legal and political impacts, these dimensions include biosafety. The biosafety system itself consists of various elements linked to the aforementioned dimensions. Traynor (1999) points out that technical guidelines are only part of a biosafety system, which also needs trained people, a review process and a feedback mechanism for improving the system. To be sustainable, additional requirements need to be satisfied. Any commitment is unlikely without participation, and compliance is unlikely without tools for enforcement. Elements of a biosafety framework, therefore, include:

- policy development, setting scope and objective and organizing public participation;
- legislation to enforce compliance with scope and objective defined;
- technical guidelines, providing technical details and setting transparent, reliable standards;
- assessment procedures, explaining the principles and procedures for decision-making;
- institutional/administrative structure that distributes and documents information;

- confidence and competence of people, often described as "human capacity"; and
- appropriate success control, an instrument for process surveillance and feedback.

Hence, policy is on top of the agenda. Many would argue that due to time pressure, technical guidelines should be the first step. Such an approach, however, ignores the logical order in which the political will determines the shape and scope of a regulatory system.

5.1 Policy Development and Legislation

Policy documents on biosafety are rarely found in developing countries (see Table 1 above). This is not surprising, given that political awareness is often still absent. Defining the scope and objectives of the biosafety system is a political decision, and a participatory approach will create awareness about the problem, existing links and available capacities. Moreover, a ratified policy document will enforce governmental commitment. Because a broad spectrum of interests and expertise is required, any participatory approach needs to create an atmosphere in which statements are substantiated, argumentation is protected from polemics, evidence and counter-evidence are considered, and positions and strategic interests are clarified and categorized (van den Daele, 1998). The North is ignoring the experience of almost 15 years of painful technology assessment and policy development, for it frequently questions the need for developing countries to institute their own biosafety policies. Assessment issues in the South, for example, differ from those in the North. Local needs and priorities, ethics, farmers' rights, indigenous knowledge, legal traditions and a different perception of globalization may also result in different conclusions (Jugessur, 1999). Since policy development must consider the present and past to project into the future, three steps are proposed:

1. Identify and describe existing regulations and policies that affect the formulation of a biosafety policy. In addition, establish and maintain contacts to key players in the public, private, governmental and scientific sectors.
2. Identify and prioritize positive and negative policy factors affecting the fields of biosafety with a focus on the dimensions of sustainable development (retrospective analysis).
3. Identify policy instruments and elements that are likely to influence the development of a sound and harmonized biosafety policy (perspective, covering public and private sector).

Step one determines the state-of-the-art and provides orientation. Experience has shown that such an effort promotes communication and mutual understanding, avoids conflicts at an early stage and facilitates the search for compliance with existing policies. It is, therefore, a valuable aid in shaping the most appropriate format of a biosafety regulatory framework. Steps two and three address the political, legal, institutional and/or economic areas and instruments as well as their expected positive or negative (or neutral) effects. A further categorization is possible in thematic or spatial dimensions (e.g., political instruments on international, regional, national, local and sectoral levels). As a result, the policy document should determine the most appropriate statutory form and also be able to legally enforce compliance with the intentions and objectives of a biosafety system. The final shape of the new legislation must be compatible with existing legislation. It should not compromise, but instead make use of existing operational regulatory structures (border patrol, plant and animal quarantine, disease control and food and feed safety). The same holds true for an institutional framework (see below). Policy-makers should request legal assistance to find a balance between flexibility and enforcement, transparency and complexity, protective and promotional elements.

Defining the scope and objective of a biosafety regulatory framework is of prime importance since it will largely define what will be subjected to risk assessment and biosafety review. Although the Cartagena-Protocol is restricted to GMOs, this does not mean that a regulatory framework should not extend beyond GMOs. In any case, the policy document and resulting legislation have to define precisely what will be regulated in terms of quality (GMOs, products of GMOs, agricultural or pharmaceutical goods, etc.) and quantity (e.g., research, industrial production, commercialization, etc., along spatial and temporal scales). More technical details are usually compiled in technical guidelines.

5.2 Technical Guidelines

The most visible and applied element of a biosafety framework is the set of technical guidelines (TGs). Several organizations have formulated model guidelines based on good laboratory practice for the handling, transport and use of GMOs and recombinant DNA. Ideally, the scope and objective of TGs will be determined within the process of policy development. Per definition, TGs will then specify respective methods, technical procedures, means and measures, definitions and classifications as determined by the policy document or as identified from other policy documents addressing biosafety issues. Widely accepted terms of reference include:

- technical description and principles of assessment procedures;
- common strategies for risk management;
- minimum standards for transport, containment and handling;
- minimum emergency requirements;
- time frame for application, notification and review;
- institutional organization and minimum requirements for qualification; and
- standard and format of applications.

For all these elements, the Cartagena-Protocol provides at least vague guidance. Most technical guidelines, however, fail to define minimum standards for qualification and expertise and do not precisely specify the allocation of duties and responsibilities within the regulatory framework. In order to minimize costs and capitalize on acquired experience, TGs should be flexible and foresee simplified procedures. On the other hand, TGs may also need to review previous assessments based upon new findings. Last but not least, TGs should also serve the applicant. Since most biosafety systems delegate the assessment to the applicant and review the application, all parties benefit when the minimum requirements of information to be provided are set (as was done by the Genetic Manipulation Advisory Committee in Australia). The responsibility for providing all relevant information remains with the applicant.

5.3 Principles and Strategies of Risk Assessment and Monitoring

The Cartagena-Protocol asks for environmental and health risk assessments based on sound science, using agreed upon principles and methods. Unfortunately, there are not very many agreed upon principles and methods. In addition, assessing the environmental risk of a GMO release requires analysis of its interaction with the environment. Assuming that the assessment has to focus on the product, not the process, one can perceive an intrinsic contradiction between the objective and scope of the Cartagena-Protocol.

Scientific risk assessment requires the identification of risk, which requires a distinction between perceived and speculative/hypothetical risks. A speculative risk, one for which no hypothesis or theory explains or describes its existence, cannot be addressed scientifically. To prove the non-existence of such an unknown risk is a logical impossibility. Of course, the available assessment tools also define the subject of assessment. It makes no sense to consider subjects that are not accessible. This restriction, however, also facilitates the identification of reasonable and appropriate procedures, technical limitations and knowledge gaps.

As mentioned above, risk assessment is not always "pure" science. Consequently, it is helpful to agree on baselines or thresholds for initiating risk assessment or categorizing assessment and management procedures (e.g., different safety levels and application procedures for containment, release and commercialization). To substantiate decisions, provide orientation and allow for the comparison of risks, assessment must be non-discriminative. Comparison requires applying identical methods irrespective of the subject – another argument for focusing on the product, not the process.

In addition to the different perceptions of risks, different assessment strategies can be defined. The *concept of familiarity* was formulated about a decade ago. It has been propagated by the OECD and the European Commission and resembles the concept of "substantial equivalence" elaborated for assessing the risks related to dangerous chemicals and novel food or feed. Many European countries have evolved biosafety frameworks that make familiarity an important component in a risk/safety analysis. Basically, the concept requires the consideration of previously acquired knowledge about the biology, trait and environment before assessing the risk/safety of a GMO. The concept concludes that GMOs, in principle, do not pose risks that are different from those posed by non-transgenic crops with similar traits in similar environments. Trait is understood as the expressed phenotype, not the underlying genotype. Several findings and factors, however, have appeared to weaken this concept. First, familiarity is a relative term. Familiarity increases with knowledge, but how can familiarity be defined when levels of uncertainty are high? Second, GMOs have characteristics that are different from non-GMOs. This neither supports or opposes a specific assessment but questions the practicability of the concept as such.

The *exotic species model* (Sukopp and Sukopp, 1993) makes long-term statements on the behavior of non-indigenous species that is in contrast to familiarity. It was hoped that the behavior of exotic species (introduced into a new environment) would provide some insight into what might happen with GMOs. In fact, most transgenic plants are cultured forms, so they appear to be quite exotic to their wild relatives. Previous experience and the sound analysis of Sukopp and Sukopp indicate that non-indigenous crops are less adapted than indigenous ones. According to a rough estimate, about 10 percent of introduced species were able to survive in their new environment, and about 10 percent of those survivors can be regarded as invasive. Yet analyses of indirect effects are rare. Moore (2000), by citing two recent publications, demonstrates the complexity of interactions within an ecosystem invaded by a new species. He identifies habitat fragmentation as a major cause of establishment and invasion of exotic species, and, indeed, it appears that exotic species are more likely to establish themselves in disturbed ecosystems. But the model makes statements based on a rather statistical basis, considers genomes versus genes, and mainly deals with non-domesticated species. So it does not offer much help in risk assessment since it has a very limited "predictive" capacity.

Horizontal assessment strategies focus on the transgene. However, "transgenic" does not comprise a category amenable to risk assessment generalizations. Conclusions about anticipated effects, moreover, cannot always be drawn from phenotypic traits – the environment as well as agricultural practices must also be considered. The horizontal concept may result in a variety of mistakes "from holding the wrong conferences, to doing the wrong risk assessment experiments and, at worst, it can contribute to specious generalizations and to flawed assumptions" (Miller, 1994). The transgene-centered approach, proposed by Nap (1999), aims to simplify the assessment procedure by analyzing the transgene irrespectively of the plant or organism into which it is introduced. The approach asks whether a particular gene and its product carries or realizes a character likely to add a risk as compared to the unmodified plant. The concept would ask for persistence, toxicity and allergenicity of the protein and the known metabolites produced or accumulated. Despite some shortcomings, especially with respect to environmental considerations, this concept partly mitigates the problems resulting from the poorly defined concept of familiarity defined above. On the other hand, this concept consolidates a transgene-oriented assessment strategy, which somehow contradicts with concentration on the technological end product.

Beside the strategic "scope", other authors have focused on the structure of risk assessment. The *hierarchical risk assessment* concept described by Rissler and Mellon (1996) proposes a step-by-step hierarchical analysis, starting with the analysis of existing information about the parent and the transgene, followed by the generation and interpretation of experimental data referring to the transgenic plant itself. The concept differs from earlier step-by-step approaches (as incorporated into almost all national and international guidelines) in that it demands experimental tests at all stages. It also requires the generation of experimental data in large-scale settings to analyze effects on non-target organisms, ecosystems and biodiversity. A few experiments have been carried out to address this part of the concept. The results did not indicate that GMOs should be categorized as a special risk as such.

Most biologists believe that there is no conceptual distinction between plants modified through classical or conventional methods (whatever conventional means, 100 years in practice, 10 years, or since human history?) or through molecular techniques, including genetic engineering. This consensus is based on the reasonable assumption that potential risk is a function of the characters of an organism and the environment into which it is introduced. The second reasonable assumption is that a tomato-breeder or farmer knows more about the behavior of tomatoes (transgenic or not) than the genetic engineer. Consequently, he/she will more likely rely on the experience made with different "conventional" tomatoes than on the experience with, for example, transgenic potatoes. These assumptions lead to an approach that can be described as *vertical risk assessment*, which to some extent integrates the concept of familiarity and the sequential procedures described above (Miller, 1994; Miller and Huttner, 1998). In short, almost all suggested models consider a sequential or step-by-step assessment procedure, following a systematic order and considering existing knowledge.

Another important topic in risk assessment is monitoring. Monitoring has become a fashionable term; however, it is very difficult to define its meaning. In the field of biosafety or environmental impact assessment, monitoring usually describes the surveillance and assessment of environmental changes and includes a feedback mechanism. In a broader sense, it involves experiments that aim to improve assessment procedures and control legal compliance. Monitoring strategies can be target-oriented. For example, it may involve the medical surveillance of a group of patients treated with a new drug, or a particular organism in an ecosystem into which a GMO has been introduced. The key issue is to define a theoretical impact and develop measures for sensing it. A feedback mechanism generates knowledge and allows the improvement of safety measures and assessment procedures. Monitoring in a situation where a potential impact has not yet been identified defines a non-target situation. The issue is not to define the theoretical impact, but to develop strategies by which any or at least many changes in the system are recognized. Non-target-oriented monitoring implicates an "open-eye-strategy" that relies on the experience and awareness of people. Although this scenario is not satisfying, it is the most powerful strategy available.

It is a major challenge to combine target-oriented and non-target-oriented strategies, since both approaches use different methods (molecular versus phenotypic), define different target-areas (managed versus unmanaged systems) and foci (event versus development). Most of the potential risks forwarded by concerned groups demand the integration of both strategies – not just with respect to GMOs. It must be kept in mind, however, that monitoring is expensive. The costs for targeted monitoring can be estimated and delegated to the applicant. In non-targeted monitoring, costs can be unlimited and it is much more complicated to delegate them. In conclusion, monitoring makes sense only if it is conceivable that an activity (or the absence of activity) is qualified to cause effects. However, one may likewise expect that impacts are likely hidden where nobody has looked for them.

5.4 Means for Implementation

The major leverages for implementing and improving a biosafety framework are the institutional and administrative frameworks (including an evaluation mechanism) and human capacity. Protecting the environment and human health while maximizing the benefits of biotechnology will generate conflicts of interest. In addition to a participatory approach in policy development, the biosafety implementation process must balance protection and promotion; it should provide a kind of intrinsic dispute procedure or structural clearinghouse mechanism. Implementation involves establishing institutional structures with competent experts who are able to realize the demands specified in scope and objective. Moreover, it entails to regulate and administer applications; carry out, document and evaluate assessment studies; monitor and supervise legal compliance; enforce measures and restrictions; evaluate emergency plans, containment and movement procedures; and educate and train personal.

Institutional Framework

Representatives of governmental institutions involved in foodsafety, agriculture, trade, health and environmental protection, science and technology and border affairs usually provide the regulatory input. The composition may vary according to the governmental structure and function and must consider the competence available within the government or its subordinate institutions. Because several governmental institutions are involved, one might delegate the decision to the ministry most involved. Another possibility might be to delegate the final decision to an inter-ministerial office. A secretariat could be responsible for accepting and distributing applications, documenting and supervising the review process, enforcing compliance with deadlines and guaranteeing the flow of information (including the recognition of confidentiality) within the regulatory system and with regulatory systems of other nations (advance informed agreement procedures). The financial costs and human resources allocated to this structure depend largely on the number of applications and the scope of the regulatory framework. The administrative organization in charge could be a subordinate governmental institution.

An advisory committee or competent body, often referred to as the national biosafety committee (NBC), should provide expertise because the scientific knowledge is usually not available elsewhere within government.

NBCs have been installed in several developing countries. A decision process circumventing or ignoring the judgement of a competent body should be avoided, and so should circumstances in which members of the competent body have to decide on their own applications. The regulatory authority, qualification standards, responsibilities, duties and election procedures, must all be defined and should be transparent. The composition of the competent body or advisory council must reflect its objectives. Economic, social, regional, cultural, religious, ethical and other issues can be subjects within the assessment process, and respective expertise should be included within the competent body or needs to be established as an additional advisory council. When the number of applications and research institutions involved in recombinant DNA-work increases, delegating responsibilities and providing for a network of surveillance and communication may be necessary and additional control levels installed. A concept of institutional biosafety committees and biosafety officers has been developed (IICA, 1988; Persley et al., 1993) and implemented in most countries with biosafety systems in place. In principle, requirements defined for the NBC apply to institutional committees alike. Technical guidelines need to specify their mode of interaction.

Developing Human Capacity

A cost-effective and reliable administrative infrastructure will fail without qualified personal. Accordingly, the policy document should contain views on the development and strengthening of such capacities. Possible measures include:

- supporting centers of excellence in biotechnology and enabling them to provide training;
- setting priorities in publicly funded research and development;
- promoting in-house training for involved ministerial departments;
- streamlining existing research and training programs and including biosafety issues;
- providing training for teachers, officials and regulatory staff;
- initiating information campaigns for relevant organizations and the public;
- promoting the participation of candidates in regional and international workshops;
- providing a training program which is regularly updated;
- capitalizing on external expertise.

Financial Implications

Within the general spectrum of modern technologies, biotechnology is a comparably cheap technology, provided that it is not burdened with inappropriate costs for assessment, reviewing, monitoring and administration. Nevertheless, biosafety has its costs, and safety measures should correspond to the risk or harm – not to their costs. The establishment and implementation of a biosafety regulatory framework requires institutional provisions, education and training of regulators, provisions for public participation, and the development of an administrative structure. The costs involved depend on the complexity, sophistication and number of applications. The scope of the regulatory system is another important determinant. Some of the costs can be covered by the applicant, including the administrative effort to carry out the assessment procedure, the costs for external review and for field trials. The degree of cost-effectiveness hinges on the magnitude of the application fees, the number of field trials, the financial capacity of the applicant and the commitment of the regulatory authority or the incentives provided by government. An assessment of financial implications, however, has to consider long-term effects and benefits, including those expected from participating in the global development and sustainable use of biodiversity. Since all these factors may vary significantly between countries, financial implications will likewise vary.

Evaluation

Almost any multi-step, interdisciplinary process will profit from identifying milestones and evaluation criteria. Milestones help identify bottlenecks and allocate resources. Another type of monitoring evaluates the process of establishing and implementing the biosafety system. Successful evaluation depends on the definition of criteria, the selection of parameters and the interpretation of results. Evaluation can take place when the process is still underway (interim), continuously, at regular intervals, on completion of the process, or long after the process has been completed (ex post), provided the process is ever completed. Defining evaluation criteria is largely based on strategies developed for research project planning in general. The strength of criteria depends on their broad acceptance and parametric value. For example, it is not sufficient to determine "institutional capacity" as a criterion if one has not agreed upon a procedure of validation.

6 THE BIOSAFETY PROTOCOL AND ITS IMPLICATIONS

The Biosafety Protocol has obviously boosted political and public awareness, especially now that countries are supposed to sign a legally binding agreement. Several articles will likely have direct implications on the establishment or modification of biosafety systems. The Protocol considers the precautionary principle (Article 1) and reflects on types of assessment procedures to be carried out in a sound scientific manner (Article 15). The precautionary principle refers to Principle 15 of the Rio-Declaration, demanding that "where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation". This is reiterated in Article 11.8 of the Cartagena-Protocol but includes risks to human health. The question is whether decision-making on risk under conditions of limited scientific knowledge is a political rather than a technical issue. The precautionary principle appears to shift the balance more towards political responsibility. This does not mean, however, that politics should substitute for scientific risk assessment. In contrast, the precautionary principle can also be understood as an incentive to close the scientific knowledge gap. The interpretation of the precautionary principle is a matter of national implementation and policy, in compliance (or conflict) with existing regional and international agreements.

Socioeconomic considerations are explicitly mentioned and should also be taken into account (Article 26), provided that this does not question other agreements, such as those of the WTO. Together with the precautionary principle, both articles will most likely outline the primary conflict with trade issues regulated under the WTO. Advance informed agreement procedures (Article 7), the establishment of national focal points and the identification of competent authorities will make communication easier and hopefully clarify responsibilities (Articles 19, 29). Despite political problems, Article 7 should be considered an excellent opportunity for addressing biosafety within regional approaches.

A third critical point, answering the question of liability and redress, has been postponed. Fortunately, a deadline has been set: the elaboration of respective rules and procedures has to be completed within four years. No suggestions for an interim mechanism were made, giving considerable flexibility to policy-makers for drafting national laws and regulations.

The Protocol is restricted to GMOs, which reflects the public debate, reiterates previous failures and mirrors the discussion in the North. However, the Protocol is a minimum requirement and does not require biosafety regulatory systems to be restricted to GMOs. Unfortunately, the Cartagena-Protocol does not provide incentives to analyze, harmonize or improve national or regional regulatory systems with respect to the import and export of “alien” species (Article 8h of the CBD). It is possible that future negotiations will result in an additional implementing protocol, specifically addressing Article 8h. In fact, the regulatory systems of Canada and the Philippines, for example, cover not only GMOs but also potentially harmful or new exotic species, without challenging the Protocol’s intention or scope. Again, this provides additional flexibility in developing biosafety frameworks, especially for those countries harboring valuable biological diversity.

Interestingly, the Cartagena-Protocol also defines several technical details. Articles 8, 9, 10, and 12 determine a time frame for deciding on applications. Developing countries with existing regulations may need to reconsider and modify respective elements. On the other hand, the schedule also demands the provision of institutional and human capacity. This needs to be considered by donor agencies and national governments alike. The addition of minimum requirements for information regarding notification for release and processing as well as guidelines for risk assessment (Annex I-III) represent important initial steps towards harmonization. Any future initiative on biosafety capacity development can build on these minimum requirements. Finally, Article 23 supports the creation of public awareness and asks for public participation. Since this is not further specified and will differ according to the “political environment” of a given country or region, the implications are difficult to determine. It could be interpreted as a request or invitation on moral grounds.

The Cartagena-Protocol put biosafety on the agenda again, including the agendas of national and international funding agencies. Indeed, the Protocol has obvious financial implications; establishing focal points, drafting guidelines and making provisions for notification and information exchange require financial and human resources. Article 28 addresses the need for financial and technical support by taking into account Articles 20 and 21 of the CBD. Creating awareness was obviously successful, but this will entail increasing requests for financial assistance and expertise in building national institutional structures and capacities (as demanded in Article 20.3 of the CBD). It is an open question at the moment whether sufficient resources will be allocated to address this development. Apart from quantitative aspects, the Protocol also demands a change in quality. The inclusion of socioeconomic considerations and the precautionary principle reveal the political and developmental dimension of biosafety, and the minimum requirements for notification and advance informed agreement are a challenge for the acquisition, analysis, documentation and management of information.

Going beyond both the Cartagena-Protocol and technical details, it is anticipated that the following key issues and requirements set the poles for an operational biosafety system:

- The biosafety framework has to reflect and consider the country's political objectives for reasons of justification, relevance and compliance.
- The biosafety framework has to be legally enforceable. Surveillance schemes have to be established and restrictive measures and sanctions have to be defined.
- Institutional and regulatory systems and technical guidelines have to be consistent in scope and objective and must be reliable in procedure and process. The policy document can be the clamp.
- The biosafety framework is embedded within existing national, regional and international regulatory systems. Where possible, it makes use of available institutional and human capacities but avoids frustrating or overtaxing these capacities.
- The philosophy and principles underlying the biosafety framework have to be named (burden of proof, discrimination, liability/compensation, proportion/justified effort, etc.).
- Impact assessment focusing on the environment and health is based on scientific principles, is not overruled and excludes social, ethical or economic questions.
- The decision system provides a decision-making process within which social, economic, cultural or ethical issues can be formulated (hearing mechanisms, communication, participation, etc.).
- The biosafety system plays an enabling role (e.g., by providing guidelines to the applicant).

In conclusion, for the time being the Cartagena-Protocol remains an ambitious piece of paper. Yet it also provides substantial flexibility for decision-makers to adapt a biosafety regulatory framework to the capacities and needs of the country. Development assistance, in turn, will need to realize the political, social, institutional, scientific and economic networks within which biosafety has to act. In addition, it needs to substantiate agreements on financial and technical support as formulated in the CBD (Article 20.3/4 and 21.4) and the Cartagena-Protocol (Article 28.3 and 28.6).

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REFERENCES

Ames, B.N., M. Profet, and L.S. Gold (1990): Nature's Chemicals and Synthetic Chemicals: Comparative Toxicology. *Proceedings of the National Academy of Science* 87, pp. 7782-7786.

APHIS (2000): Data Sheets. Animal and Plant Health Inspection Service, United States Department of Agriculture, Retrieved from the internet: www.aphis.usda.gov/bbep/bp.

van den Daele, W. (1998): Risk Prevention and the Political Control of Genetic Engineering: Lessons from a Participatory Technology Assessment on Transgenic Herbicide-Resistant Crops. *AgBiotech News and Information* 10 (11), pp. 355-358.

Darmency, H. (1994): The Impact of Hybrids Between Genetically Modified Crop Plants and their Related Species: Introgression and Weediness. *Molecular Ecology* 3, pp. 37-40.

Daszak, P., A.A. Cunningham, and A.D. Hyatt (2000): Emerging Infectious Diseases of Wildlife – Threats to Biodiversity and Human Health. *Science* 287, pp. 437-449.

FAO (2000): Statistics Database. Food and Agriculture Organization of the United Nations, Retrieved from the internet: www.fao.org.

Hoyle, B. (1999): Canadian Farmers Seek Compensation for Genetic Pollution. *Nature Biotechnology* 17, pp. 747-748.

IICA (1988): *Guidelines for the Use and Safety of Genetic Engineering Techniques or Recombinant DNA Technology*. Inter-American Institute for Cooperation on Agriculture, Washington, D.C.

James, C. (1999): Global Review of Commercialized Transgenic Crops: 1999. ISAAA Briefs, No.12, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

James, C. (1997): Global Status of Transgenic Crops in 1997. ISAAA Briefs, No. 5, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

Jugessur, S. (1999): Policy Framework for the Development and Application of Biotechnology in Africa. Proceedings of the All Africa Biotechnology Workshop, 8-10 September, Algiers, Algeria

de Kathen, A. (1999): Transgenic Crops in Developing Countries: A Report on Field Releases, Biosafety Regulations and Environmental Impact Assessment. Texte 58/99. Umweltbundesamt, Berlin.

Kok E.J., and H.A. Kuiper (1996): Evaluation of Strategies for Food Safety Assessment of Genetically Modified Agricultural Products – Information Needs. *Food Safety Evaluation*, pp. 80-84.

Miller, H.I. (1999): Substantial Equivalence: Its Uses and Abuses. *Nature Biotechnology* 17, pp. 1042-1043.

Miller, H.I. (1994): Risk-Assessment Experiments and the New Biotechnology. *Trends in Biotechnology* 12, pp. 292-295.

Miller, H.I., and S.L. Huttner (1998): A Baroque Solution to a Nonproblem. *Nature Biotechnology* 16, pp. 698-699.

Moore, P.D. (2000): Alien Invaders. *Nature* 403, pp. 492-493.

Nap, J.P. (1999): A Transgene-Centered Approach to the Biosafety Assessment of Transgenic Herbicide-Tolerant Crops. *Biotechnology and Development Monitor* 38, pp. 6-11.

OECD (1997): Safety Assessment of New Foods: Results of an OECD Survey on Serum Banks for Allergenicity Testing and Use of Databases. General Secretariat, Internal Coordination Group for Biotechnology, SG/ICGB (97)1, Organization for Economic Cooperation and Development, Paris.

Persley, G.J., L.V. Giddings, and C. Juma (1993): Biosafety: The Safe Application of Biotechnology in Agriculture and the Environment. Research Report, No. 5, International Service for National Agricultural Research, The Hague.

Redenbaugh, K., W. Hiatt, B. Martineau, J. Lindemann, and D. Emlay (1994): Aminoglycoside 3'-Phosphotransferase II (APH(3')II): Review of its Safety and Use in the Production of Genetically Engineered Plants. *Food Biotechnology* 8, pp. 137-165.

Rissler, J., and M. Mellon (1996): *The Ecological Risks of Engineered Crops*. The MIT Press, Cambridge, MA.

Sukopp, H., and U. Sukopp (1993): Ecological Long-Term Effects of Cultigens Becoming Feral and of Naturalization of Non-Native Species. *Experientia* 49, pp. 210-218.

Syvanen, M. (1999): In Search for Horizontal Gene Transfer. *Nature Biotechnology* 17, pp. 833.

Taylor, S.L. (1996): Assessment of the Allergenicity of Genetically Modified Foods. Document retrieved from the internet: www.bdt.org.br/Library/cabi/taylor.htm.

Torgersen, H. (1996): Ecological Impacts of Traditional Crop Plants – A Basis for the Assessment of Transgenic Plants? Monograph No. 75, Federal Environment Agency of Austria, Vienna.

Traynor, P.L. (1999): Biosafety Management: Key to the Environmentally Responsible Use of Biotechnology. In: J.I. Cohen (ed.). *Managing Agricultural Biotechnology – Addressing Research Program Needs and Policy Implications*. CAB International, Wallingford, UK, pp. 155-165.

UNDP (1999): *Human Development Report 1999*. United Nations Development Project, New York.

Virgin, I., and R.J. Frederick (eds.) (1996): *Biosafety Capacity Building: Evaluation Criteria Development*. Stockholm Environment Institute, Biotechnology Advisory Commission, Stockholm.

PART II

REGIONAL OUTLOOK

OVERVIEW

Usha Barwale Zehr

The total global acreage of transgenic crops has dramatically increased during the last three years. Much of this increase has taken place in developed nations. Biotechnology-derived products, however, have an essential role to play in Latin America, Africa, and Asia, as developing countries move towards their goal of achieving sustainable agricultural development. Indeed, the current situation of unsustainable agricultural practices, crop yields below global averages and declining land availability for agriculture cries out for biotech solutions.

The biotechnology debate in North America and Europe is affecting decision-making in many developing countries. The real questions, however, related to releases of transgenic material in developing countries are not being addressed. Is the technology good for the farmer (both small and large farms)? Is it safe? And who will be the ultimate beneficiary of this technology? The debate for the developing countries should focus on the following:

- What technologies do local farmers require?
- If unavailable locally, can these technologies be transferred from other countries?
- If found appropriate for farmers' needs in a given region, are biosafety regulations in place to ensure that the material can be locally tested and released?

M. Qaim et al. (eds.),
Agricultural Biotechnology in Developing Countries: Towards Optimizing the Benefits for the Poor, 69–71.

We must also ask whether developing countries can afford to miss this technology-driven agricultural revolution. Many feel that the impact of the green revolution was not fully realized; the same might be true for agricultural biotechnology if we do not vigorously pursue a rational debate about its risks and benefits.

The three papers in this "Regional Outlook" provide information relevant to all developing regions. For Latin America and the Caribbean (LAC), *Eduardo Trigo* discusses the capability of the scientific community and the infrastructure capacity of this region in regards to biotechnology. The larger countries of the LAC region have established a number of advanced biotechnology research programs, but the commercial effectiveness of these programs is still limited. And although Argentina, Brazil and Mexico are already growing genetically modified organisms (GMOs), the related products have been developed and commercialized by foreign companies. The main constraints for the exploitation of local LAC capacities are underinvestment, unclear research priorities and deficient links between basic and applied research. Policy-makers are also confused by the lack of biotechnology acceptance in some of their main export markets for agricultural commodities produced in this region.

The challenges facing Africa are well documented by *Florence Wambugu*. Because local research capacities are still underdeveloped in Africa, suitable biotechnologies have to be imported from abroad. Wambugu emphasizes how strategically introducing technology in African nations can lead to local capacity building and widespread technology adoption through regional cooperation and spillovers. Such results, however, require both efficient biosafety regulations and a favorable institutional and policy framework for the large-scale distribution of approved biotechnology applications. As the development of tissue culture banana plants in Kenya has shown, given suitable transfer mechanisms, even comparatively simple biotechnology products can have tremendous positive impacts on both small and large farms.

The chapter on Asia by *Mahabub Hossain et al.* provides insights into what technological interventions can address food security and poverty issues in Asia. Using rice as an example, the paper vividly shows that biotechnology research can be specifically designed for problems in developing countries. Improving stress resistance mechanisms and enhancing the nutritional value of rice will provide major benefits for the poor. But technologies tailored to marginal lands (i.e., resistances to abiotic stresses) have so far suffered from a lack of research, notwithstanding the important benefits such research could provide. This research would also be most useful for farmers who have largely been bypassed by the green revolution.

These papers make clear that technologies are already available to serve the needs of poor smallholder farmers. Yet there are financial as well as institutional obstacles that hinder the full exploitation of this biotechnology in the developing world. In the meantime, in each region there are one or two countries better positioned to take the lead on the biotechnology front. The lessons they learn must be shared with other countries in the region.

Biotechnology research is resource intensive and time consuming. Many of the available technologies are owned by the private sector from the developed world. To take advantage of these technologies, innovative forms of partnerships are now required between public institutes, the private sector and non-governmental organizations. The mutual distrust between these different groups must be overcome, since solutions for the poor can only be developed in a joint effort involving all stakeholders. Furthermore, biotechnology transfer and implementation would be much more effective if there was better intra-regional cooperation.

The biotechnology debate today is a debate about transgenic crop technology. Yet the example of tissue culture bananas in Kenya shows that non-transgenic biotechnologies are equally important and valuable – although so far underutilized. Accordingly, for the right technology to be tested and – if found appropriate – deployed, policy platforms that allow for the evaluation of both transgenic and non-transgenic material must be established. Finally, for developing nations to fully realize the benefits of biotechnology products, decisions at all policy levels must be both timely and made within the context of a long-term horizon.

Chapter 5

THE SITUATION OF AGRICULTURAL BIOTECHNOLOGY CAPACITIES AND EXPLOITATION IN LATIN AMERICA AND THE CARIBBEAN

Eduardo J. Trigo

Abstract: Agricultural biotechnology research and related support activities in Latin America and the Caribbean began in the late 1970s. With few exceptions, however, these activities have not evolved as expected, particularly as regards the commercial exploitation of biotechnologies. Apart from comparatively simple techniques, such as diagnostics and micropropagation, most activities at the commercial level are linked to the importation and release of technologies developed by multinational companies. For the most part, the region's national agricultural research systems are too fragmented and they do not take advantage of the potential benefits of partnerships between the public and private sectors. Furthermore, little emphasis in biotechnology research is placed on tackling the problems of resource-poor farmers. Overall, chronic underinvestment in general agricultural research – and particularly in agricultural biotechnology – is the region's most serious problem with respect to related innovation development.

1 INTRODUCTION

Agricultural biotechnology research and development (R&D) has been going on in Latin American and Caribbean (LAC) countries since the late 1970s. It has been concentrated mostly in the larger countries of the region, but a number of the smaller ones have also been active participants. Currently, several biotechnology products are already reaching the market. This paper attempts to summarize the evolution of agricultural biotechnology in these countries during the last few decades, what is happening today, and what the future could hold. The paper is organized in

M. Qaim et al. (eds.),
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five sections, including this introduction. The second section profiles the region's R&D capacities and their relative emphases in terms of species and areas of application. The third section reviews the status of support institutions, including national and international cooperation programs, as well as the important issues of intellectual property rights (IPRs) and biosafety regulations. The status of the industrial exploitation of these new technologies is examined in the fourth section, and the final section attempts to highlight what, in the opinion of the author, are some of the factors that will affect the future development of this industry in LAC countries.

2 RESEARCH AND DEVELOPMENT CAPACITIES

The LAC region was an early participant in agricultural biotechnology. By the late 1980s, quite a few LAC countries had already established notable biotechnology research activities. Many institutions created specific structures (institutes or centers) for biotechnology, such as the Biotechnology Institute of the National Autonomous University and the Irapuato Unit of the Center for Research and Advanced Studies (CINVESTAV) in Mexico, the Genetic Engineering and Biotechnology Institute of Cuba, the National Center for Research on Genetic Resources and Biotechnology of the Brazilian Enterprise for Agricultural Research (EMBRAPA), the Center for Molecular Biology of the National Agricultural Technology Institute (INTA), and the Center for Genetic Engineering of the National Council for Scientific and Technological Research (CONICET) in Argentina, among others. Other institutions promoted biotechnology activities through projects based in existing research units within universities and other public research centers. Most of these initiatives were not conscious government efforts to develop the biotechnology industry but were instead driven by the science sector. Only Cuba put in motion what could be considered an integral national program to develop a biotechnology industry, which integrated support for both R&D and the industrial exploitation of useful results. Still, other LAC countries achieved a critical mass of scientists working on biotechnology topics, a capacity that today serves as a good basis for industrial undertakings that could commercially exploit the new technologies.

According to a survey undertaken by Mexico's Chapingo University and the International Center for Tropical Agriculture (CIAT), in 1986 about 95 institutions located in Cuba, Brazil, Argentina, Trinidad & Tobago, Chile, Mexico, Venezuela, Costa Rica, Uruguay, Colombia and Peru, reported some biotechnology capacity that together involved slightly more than 900

Table 1: Distribution of human resources in agricultural biotechnology by type of organization (percent)

Type of Organization	Human Resources
Private (company or private institutes)	12.2
Public agricultural institute	34.3
Public non-agricultural institute	3.7
University (agr. and non-agr.)	41.2
IARCs	3.7
Non-agricultural international center	-.-
Other	4.9

Sources: Jaffé and Zaldívar (1993); Roca et al. (1998); Jaffé and Infante (1996).

people (Roca et al., 1998). Another study by the Interamerican Institute for Cooperation on Agriculture (IICA, 1992) referred to statements of 155 experts during the late 1980s to conclude that Argentina, Brazil, Chile, Costa Rica, Mexico, Uruguay and Venezuela (Cuba was not included in the study) had relatively advanced biotechnology capacities and that they were capable of handling some modern, highly complex techniques. A second group, formed by Colombia, Peru and Trinidad & Tobago, could handle work of intermediate complexity, while the remaining countries had only incipient or no capacities at all. The IICA study identified about 140 research groups or institutions with R&D capacities in agricultural biotechnology. Thirty-five of these groups could be described as "well established" given their scientific potential, since they possessed capacities in traditional biotechnology (fermentation, tissue and cell culture, immunology, and embryo technologies) and in some cases also had capacity in molecular biology and other more advanced techniques. Universities and other public sector research institutions accounted for the largest segment of capacities (see Table 1). A few regional international agricultural research centers (IARCs) of the Consultative Group on International Agricultural Research (CGIAR), such as CIAT, the International Potato Center (CIP), and the International Center for Maize and Wheat Improvement (CIMMYT) also played an active role, especially the first two, who were leaders in their mandated crop and human resources development. Only a small fraction of the biotechnology researchers worked in companies and private research institutions.

This general situation was confirmed by another study of 150 laboratories in 15 countries (Argentina, Bolivia, Brazil, Colombia, Costa Rica, Cuba, Chile, Dominican Republic, Ecuador, El Salvador, Guatemala, Mexico, Peru, Uruguay, and Venezuela) undertaken in 1989-90 (Villalobos, 1997). According to this study, there were over 1,000 researchers in these countries at work on biotechnology-related areas. Almost 50 percent of them were concentrated in academic institutions (universities), while other public R&D institutions and private companies accounted for 35 percent and 18 percent of the personnel, respectively. Sixty-three percent of the research projects were in cell and tissue culture, particularly in micropropagation. In decreasing order of importance, other areas included germplasm conservation (10.1%), disease diagnosis (10.1%) genetic engineering and molecular biology (8.6%), protein research (3.7%), and tolerance to adverse environmental factors (2.7%). In terms of crop species, fruits were the most important, accounting for 19 percent of all projects, followed by industrial crops (10.2%), vegetables (8.9%), cereals (8.0%), woody species and ornamental plants (7.7%), roots and tubers (7.2%), pulses (4.8%), and fodder crops (2.9%).

Scientific production indicators also confirm that the region is interested in these technologies, but that capacities are concentrated in only a few countries and institutions. A study of publications in *Biological Abstracts* for the period 1978-87 shows that only eight countries had more than 10 articles on biotechnology issues and topics. Furthermore, only four countries – Brazil, Mexico, Argentina, and Cuba – published about 85 percent of all the articles (see Table 2). As reported by Jaffé and Infante (1996), more recent data from the Commonwealth Agricultural Bureau International (CABI) (*AgBiotech News and Information*) shows a similar level of concentration. Universities were the source of more than 65 percent of these published articles, followed by the non-agricultural research centers. Agricultural research institutions, both national and international, were not significant sources of publications, although they possessed a significant share of the scientific capabilities (Table 3).

Table 2: Number of articles related to agricultural biotechnology published by LAC countries

Country	Biological abstracts 1978-87	AgBiotech News and Information 1993	Int. Plant Molecular Biol. Congress 1994
Brazil	648	14	6
Argentina	179	9	7
Mexico	212	21	23
Cuba	118	3	0
Chile	65	7	0
Colombia	17	1	0
Venezuela	40	0	2
IARCs	56	7	8

Sources: Jaffé (1993), Jaffé and Infante (1996).

Table 3: Publications on agricultural biotechnology by type of organization (percent)

Type of organization	Intermediate Biotech	Modern Biotech
Private (company or private institute)	1.4	1.0
Public agricultural institute	15.2	3.0
Public non-agricultural institute	12.2	21.6
University (agr. and non-agr.)	65.4	69.1
IARC	3.5	1.0
Non-agricultural international center	0.8	0.0
Other	1.5	4.2

Sources: Jaffé and Zaldívar (1993); Roca et al. (1998).

During the last decade, R&D capacities seem to have evolved and consolidated along these observed trends. Although more recent studies with quantitative indicators are unavailable, different sources from within the scientific community suggest that agricultural biotechnology capacities have consolidated in a small number of countries: essentially the larger ones (Brazil, Mexico, Argentina) and those who began work early in this field, such as Venezuela, Chile, Uruguay, and Costa Rica. Cuba likely continues to have the most balanced R&D capacities, if not the largest. This view is consistent with sources for papers presented at the most recent Latin American Meeting on Plant Biotechnology, REDBIO '98, which took place in La Habana, Cuba, June 1-5, 1998 (FAO, 1998). Excluding Cuba, only 13 countries presented papers, and of these, only Brazil, Argentina, and Mexico

Table 4: R&D in transgenic crops in LAC (1998/99)

Country	Crops
Argentina	Potato, sunflower, lupine, alfalfa, wheat, tomato, soybean, cotton, maize
Brazil	Potato, sugarcane, peanut, tobacco, alfalfa, maize, fruits, vegetables
Chile	Potato, vegetables, berries
Colombia	Rice, cassava, flowers
Costa Rica	Fruits, coffee, cocoa
Cuba	Rice, banana, sweetpotato, coffee, sugarcane, tobacco, fruits, potato
Mexico	Potato, maize, vegetables, coconuts
Peru	Potato
Trinidad & Tobago	Cocoa, flowers
Uruguay	Potato, rice
Venezuela	Potato, fruits

Sources: FAO (1998) and personal information.

Table 5: R&D in cell and tissue culture in LAC (1998/99)

Country	Crops
Argentina	Sunflower, forestry species, vegetables (asparagus, onion, garlic, tomato), rice, forages, fruits (grape, olive), "Yerba mate", medicinal plants, ornamental plants, sugarcane, potato
Brazil	Forestry species, fruits(guava, mango, papaya), cashew, medicinal plants, banana, plantain, cassava, potato, sweetpotato
Caribbean countries	Ornamental plants, banana, plantain, coffee, rice, cocoa, coconut, forestry species
Chile	Fruits (grape, olive), vegetables (onion, garlic), forestry species, ornamental plants
Colombia	Potato, cassava, rice, bean, coffee, forestry species, aromatic herbs
Costa Rica	Forestry species, ornamental plants, coffee, potato, banana, plantain, cocoa
Cuba	Rice, sugarcane, coffee, sweetpotato, potato, vegetables (tomato), banana, plantain, bean, fruits (papaya, pineapple)
Mexico	Potato, coffee, onion, ornamental plants, grape, coconut, agave, aromatic herbs
Uruguay	Potato, onion, forestry species, fruits, rice
Venezuela	Potato, medicinal plants, fruits(melon, maracuya), coffee, banana, plantain, cocoa

Sources: FAO (1998) and personal information.

were represented in all 10 conference sections.[1] Venezuela, Chile, Costa Rica, Colombia, and Uruguay presented work in at least three of the sections. Most papers concerned cell and tissue culture, but there were also some reports on genetic markers, genetic engineering, and other molecular biology techniques, including an important emphasis on diagnostics aimed at a wide range of areas. Tables 4 and 5 present a summary of the main work underway organized by countries and crops. It is difficult to disaggregate this information by traits, but particularly in the case of transgenics, an analysis of the REDBIO '98 papers and other available sources indicates that input characteristics dominate (mainly herbicide tolerance, insect protection and virus resistance, and to a lesser extent drought tolerance and other soil and fertility deficiencies). There are no reports of significant work in the so-called second generation of biotechnologies, those that promise such product quality improvements as ripening regulation, extended shelf life, improved protein content, and other nutritional benefits.

The Havana meeting also suggests that universities (no distinction between agricultural and non-agricultural) are the most active institutions

[1] The ten sections were the following: Tissue culture, crop improvement and genetic conservation, genetic markers, transformation, metabolism, abiotic stress, biotic stress, diagnostics, biocontrol, and bioproducts.

and that, once more, the agricultural research institutes appear active only in larger countries. It is worth noting, however, that non-university institutes seem to put a relatively higher share of their work in diagnostics and are closer to working on applied research, or even adaptive research.

3 BIOTECHNOLOGY DEVELOPMENT SUPPORT INSTITUTIONS

In general, introducing biotechnology – especially agricultural biotechnology – involves significantly departing from established scientific and institutional infrastructures. In terms of R&D, biotechnology requires tightly integrating basic disciplines into research strategies and establishing better links between agricultural research institutes and academic research institutions that are working on basic and strategic research issues. From an institutional and economic point of view, intellectual property issues and biosafety considerations, which are important but not critical for traditional technologies, become crucial. Furthermore, programs and policy initiatives that speed up capacity formation and/or a climate of investment and public acceptance are of the utmost importance for industry consolidation.

3.1 Biotechnology R&D Support Programs

Most of the biotechnology developments reported in the previous section have evolved *pari pasu* with a number of support programs aimed at developing scientific capacities at the country, regional, and subregional levels. These programs have concentrated mainly on creating and consolidating the local R&D base, and have not begun research valorization or commercial exploitation. In most cases, they have combined R&D and infrastructure development funding with human resources training. Argentina, Brazil, Colombia, Costa Rica, and Venezuela, for example, have had programs of this type, funded in part by international science and technology support from the Interamerican Development Bank (IDB) and the World Bank (WB) (Table 6).

The emphasis in human resources has mostly been on PhD training abroad. Not enough attention has been paid to training technical and lab personnel and intermediate level researchers (MSc) or to continuing the education of already established scientists. But the IARCs, notably CIAT, have had an important role in these efforts through their short-term training, post-doc, and residents programs.

Table 6: Selected governmental programs supporting biotechnology development in LAC

Country	Names and dates	Responsible organization	Components	Investment (mill. US$)
Argentina	National Biotechnology Program	Department of Science and Technology (SeCyT)	Promotion and funding of R&D	3.8
Brazil	National Biotechnology Program (1981)	Nat. Research Council (CNPq) and Nat. Fund for the Promotion of Scient. and Technol. Research (FINEP)	Funding of R&D	3.3
	Science and Techn. Program, Biotech (1984)	Ministry for Science and Technology (supported by WB)	Human resources and infrastructure	12.9
	Biotechnology parks	Ministry for Science and Technology	Infrastr. and services for startup comp.	n.a.
Chile	National Biotechnology Committee (1983)	National Council for Scientific and Technological Research (CONICYT)	Human res., R&D promotion and coord.	n.a.
Colombia	Biotechnology Program (1984)	Colombian Scientific Council (COLCIENCIAS)	R&D planning, coord. and funding	n.a.
Venezuela	National Biotechnology Program (1986)	Council for National Scientific and Technological Research (CONICIT)	Funding of R&D	0.5
	Program of New Technologies (1992)	CONICIT (supported by IDB)	Human res., infrastr. and funding of R&D	30.0

Source: Developed by the author on the basis of Jaffé and Infante (1996) and personal information.

International cooperation programs have also played a significant role in the development of biotechnology, especially in the smaller countries (see Table 7). The most relevant programs include the Regional Biotechnology Program of the United Nations, the United Nations Development Program (UNDP), the United Nations Education and Science Organization (UNESCO), and the United Nations Industrial Development Organization (UNIDO), which pioneered the process of technology diffusion in many of the region's research institutions by funding cooperative projects involving institutions in different countries. The international programs also assisted in the creation of a number of "national biotechnology commissions" and in coordinating individual national efforts. Other initiatives, such as the Biotechnology Program for Latin America and the Caribbean (BIOLAC),

Table 7: Regional biotechnology cooperation programs

Dates	Title	Agency	Scope	Budget (thousand US$)
1988-93	Regional Biotech Program	UNDP/UNESCO /UNIDO	Regional	5,000
1988-	BIOLAC	University of the United Nations	Regional	150-200 per year
1990-	REDBIO	FAO	Regional	60 per year
1988-93	Andean Biotech Program	Andean Support Corporation	Andean region	2,000
1988-94	Agricultural Biotech Policies	IICA	Regional	800 per year
1988-	Biotechnology	Org. of American States (OES)	Regional	300 per year
1992-	Conosur Biotech Program	PROCISUR, IICA	Southern cone	120 per year

Source: Jaffé and Infante (1996).

the Program of the United Nations University and the Agricultural Biotechnology Network (REDBIO) of the Food and Agriculture Organization (FAO), focused on creating basic research capacities. At the subregional level, there are several programs designed to develop cooperative research, technology transfer, and the sharing of information on issues of common interest. Among these, the Cooperative Agricultural Research Program for the Southern Cone (PROCISUR, 1997), which links Chile, Argentina, Uruguay, Brazil, Paraguay, and Bolivia, has probably made the most notable impact and has maintained the most support from participating countries and international assistance organizations.
IARCs, particularly CIP, CIAT, and the Central American Center for Tropical Agricultural Research and Education (CATIE), have also been critical supporters for regionally developing biotechnology. CIP has played a critical role in diffusing tissue culture in roots and tubers, and the biotechnology unit of CIAT – one of the most advanced research groups in the region – has played a strategic role in strengthening national capacities through networking and training activities.

Support for biotechnology R&D recently seems to have significantly shifted from specialized programs (as described above) to horizontal programs oriented towards supporting R&D activities in general, usually within the framework of competitive funding schemes.[2] There are no

[2] Venezuela (CONICYT), Chile National Fund for Scientific and Technological Research (FONDECYT), National Fund for Technological Development (FONTEC), and National Fund for Development Promotion (FONDEF), Uruguay National Council for Scientific and Technological Research (CONICYT), Argentina National Fund for Science and Technology

comprehensive data about how large biotechnology's share of these projects is in terms of the total funding provided through these schemes, but partial evidence from some countries (Chile, Argentina, Venezuela) indicates that biotechnology-related work possessed a significant share from the beginning. In the case of Argentina, for example, of the more than 1,100 projects approved by FONCYT in 1997 and 1998 almost 30 percent can be categorized as biotechnology R&D.

Another important development is that these initiatives include significant funding (soft loans and grants) for (i) scientific institutions to develop better links with the productive sector, and (ii) technological modernization and innovation at the individual company level. FONTAR and FONCYT in Argentina, FONDECYT, FONDEF and FONTEC in Chile, and CONICYT in Venezuela, all offer co-funding to allow R&D institutions (public and private) to establish business units. This allows them to improve their capacities to provide technological services, facilitates the promotion of joint ventures between companies and research institutions in R&D activities, and encourages commercial companies to directly fund R&D and innovation initiatives. All these initiatives have been developed with funding assistance from the IDB. They provide critical support not only for research activities but also for technology transfer. Although they are not a replacement for venture capital, they are an important step in facilitating the link between scientific and technology exploitation capacities.[3]

3.2 Intellectual Property Rights

Given the proprietary nature of biotechnologies and their commercial potential, IPR issues are important for industry development. The region's IPR situation is highly diverse and constantly evolving, with only a very few countries possessing a well defined, stable IPR framework. IPR management should consider two different aspects: patent legislation and plant breeders' rights. In the past few years, Mexico, some of the Andean countries, Chile, and Argentina have revised their patent legislation to allow for the protection of microorganisms and processes based on them, as well as pharmaceuticals and food products.[4] These changes may be too recent to have any impact on industry development. In the future, however, once the flow of marketable

(FONCYT) and Argentinean Fund for Technology Development (FONTAR) among other initiatives.

[3] In Argentina, FONTAR has funded a number of collaborative projects with biotechnology companies and provided support for the establishment of biotechnology-based service units at INTA.

[4] The patenting of other living organisms is still not allowed in any of the LAC countries.

biotechnology products increases, they are expected to become more important.

Plant breeders' rights have a longer history in the region. Argentina, Chile, and Uruguay have had legislation addressing such issues for about 20 years, although it was fully implemented only in the mid 1980s. Since then Mexico, the Andean Pact countries, Brazil, and Costa Rica have also adopted such legislation. A study conducted by the University of Amsterdam and IICA (reported in Jaffé and van Wijk, 1995) shows that the impact of this legislation is low, even in those countries that have had it for a long time. The report also indicates, however, that this legislation has an important indirect impact by strengthening local breeding programs, particularly in open-pollinated species, and by improving local industry's access to advanced varieties. This latter impact is of greatest significance for fruits and flowers.

3.3 Biosafety Regulations

Biosafety is one of the key policy instruments for the development and exploitation of biotechnology as well as for international biotechnology transfer. Some of the LAC countries were among the first to establish national biosafety regulations in the developing world. With the assistance of the Pan-American Health Organization (PAHO) and later IICA, a process was initiated in the second half of the 1980s to first develop biosafety guidelines for laboratory and industrial handling of biotechnology processes and products (particularly those involving recombinant DNA technologies). Later on, guidelines for the release of genetically modified organisms (GMOs) into the environment were developed, both for field-trial purposes and for product commercialization. Argentina, Mexico, Brazil, Costa Rica, Bolivia, Uruguay, and Chile have adopted specialized committees to evaluate and supervise trials and releases, which will be based on the adaptation of existing phytosanitary regulations.[5]

4 THE STATE OF INDUSTRIAL EXPLOITATION OF BIOTECHNOLOGY PRODUCTS

Comprehensive information about the biotechnology industry in the LAC region is not readily available. A profile of the industry, however, is possible through a consideration of the status of field trials and of the

[5] Brazil has opted for special legislation, rather than using the existing phytosanitary regulatory framework.

commercialization of transgenic crops. Moreover, biotechnology companies registers, which exist for some of the countries (Mexico, Brazil, Argentina), can be analyzed.

Although genetic transformation work is ongoing in a relatively large number of countries for many products (see Table 4), commercial exploitation is taking place in only a few countries and for a limited list of species. Argentina is the country with the longest and most important experience in the field, having approved 118 field trials between 1991 and 1996, 78 in 1997, and 90 in 1998. Table 8 summarizes the distribution of field trials by species. In 1996, herbicide-tolerant soybean (Monsanto's Roundup Ready soybean) was authorized for commercial release. The area cultivated with this product has grown dramatically since then to reach more than 5.5 million hectares in 1998, about 65 percent of Argentina's total soybean area. In 1999, *Bacillus thuringiensis* (Bt) maize was also approved, and it is expected that Roundup Ready maize and cotton, as well as Bt cotton and sunflower will follow soon.

Up to 1998, Brazil has approved 54 field trials, most of them in soybean, maize, and sugarcane, which have been transformed for herbicide tolerance and insect resistance. In 1998, Roundup Ready soybean was approved for commercial release. Its diffusion, however, has been slowed down in part by divergent policy decisions between governments at the federal and state level. Due to the biotechnology acceptance problems in some of the main soybean importing countries, some state governments banned transgenic products in an attempt to gain comparative advantages.

Through 1998, Mexico approved 18 field trials and some commercial releases in cotton (herbicide tolerance and Bt, commercial), alfalfa, rice (virus resistance), squash (virus resistance), canola (oil quality, herbicide

Table 8: Field trials of transgenic crops approved in Argentina (1997-98)

	1997		1998	
Product	Number	Percent	Number	Percent
Maize	41	52	40	44
Sunflower	17	22	24	27
Soybean	7	9	12	13
Cotton	7	9	4	5
Wheat	2	3	2	2
Potatoes	2	3	3	3
Alfalfa	1	1	4	5
Tomatoes	1	1	0	0
Rice	0	0	1	1
Total	78	100	90	100

Source: Banchero et al. (1999).

resistance, commercial), chili (delayed ripening), maize (herbicide tolerance and insect resistance), melon (virus resistance), potatoes (virus resistance), soybeans (herbicide tolerance, commercial), tobacco (virus resistance), tomatoes (insect resistance, delayed ripening, commercial), and wheat (gene markers).

Other countries that already have conducted transgenic field trials include Chile, Costa Rica, and Uruguay, which have approved soybeans (herbicide tolerance) and maize (herbicide tolerance and insect resistance). But most of the work in these countries is not yet ready for domestic commercial release. Most applications have been submitted by foreign companies so that they can test their products under different agroecological conditions.

Existing surveys indicate that in 1991-92 there were about 260 companies using biotechnology processes or products in 14 LAC countries. Of these, the largest number (55%) were in the agricultural sector, including agricultural inputs (seeds, inoculants, pesticides, fertilizers, diagnostics, and veterinary products) and agro-industry (food processing, cellulose, and alcohol production). The remainder was in the pharmaceutical and chemical industry (see Table 9). Disaggregating by country, the distribution of companies follows the structure of scientific capacities: the more advanced countries (Argentina, Brazil and Mexico) also have the most companies. But Uruguay and Costa Rica (both with a strong agricultural export orientation)

Table 9: Latin American companies that utilize biotechnology (1991/92)

	Sector						
Country	Agr. inputs	Human health	Chemi-cal	Agro industry	Envir. protect.	Other	Total
Argentina	22	10	2	2	0	1	37
Bolivia	7	0	0	0	0	0	7
Brazil	20	15	14	5	4	14	72
Chile	2	1	0	3	0	1	7
Colombia	9	0	0	2	0	2	13
Costa Rica	15	2	0	1	0	0	18
Ecuador	4	3	1	2	0	0	10
El Salvador	1	0	0	0	0	0	1
Guatemala	3	1	0	1	0	1	6
Honduras	0	1	0	0	0	0	1
Mexico	5	1	17	6	1	4	34
Peru	2	2	1	0	0	2	7
Uruguay	10	2	2	5	0	2	21
Venezuela	19	4	0	0	0	6	29
Total	119	42	37	27	5	33	263

Source: IICA (1992, 1993).

Table 10: Characteristics of LAC biotechnology companies (percent of total 1991/92)

	Type		Ownership		
Country	Newly established	Existing	Local	Foreign	Government
Argentina	32.4	67.5	89.1	10.8	0.0
Bolivia	85.7	14.2	28.5	0.0	71.4
Brazil	40.2	59.7	65.2	25.0	9.7
Chile	14.2	85.7	100.0	0.0	0.0
Colombia	30.7	69.2	76.9	7.6	15.3
Costa Rica	66.6	33.3	61.1	22.2	16.6
Ecuador	30.0	70.0	30.0	70.0	0.0
El Salvador	0.0	100.0	0.0	100.0	0.0
Guatemala	50.0	50.0	100.0	0.0	0.0
Honduras	0.0	100.0	0.0	0.0	100.0
Mexico	38.2	61.7	67.6	26.4	5.8
Peru	28.5	71.4	100.0	0.0	0.0
Uruguay	38.1	61.9	80.9	19.0	0.0
Venezuela	68.5	34.4	75.8	3.4	20.6
Average	42.5	57.4	71.4	18.6	9.8

Source: IICA (1992, 1993).

also have a relatively large number of companies (21 and 18, respectively). This clearly indicates the region's level of commitment to biotechnology industry development.

Along similar lines, it is interesting to note that a large proportion of the companies, about 40 percent, were new companies created specifically to exploit a given technological development, and 70 percent of them were locally owned. The rest were subsidiaries of transnational corporations and government-owned companies (Table 10). In relation to agriculture, the technologies most frequently used are plant tissue culture techniques (propagation in roots and tubers, fruits, and ornamental plants), immunology technologies (veterinary diagnostic kits), and the production of biopesticides. Work on transgenics was reported in only a very few cases.

The figures presented in Table 10 may be misleading, however, in respect to the industry's real economic structure for more advanced biotechnology products. When analyzing the origin of companies submitting requests for permits to test and commercialize GMOs in crops of greater economic importance – evidently the market segment of higher economic value – the greatest share of the applications are concentrated in transnational corporations (Table 11).

Table 11: Field trials of transgenic crops in Argentina and Brazil by company (1997/98)

	Argentina		Brazil	
Company	Number	Percent	Number	Percent
Nidera S.A.	27	18	0	0
Monsanto	20	13	12	24
Cargill Seeds. M.	20	13	6	12
Novartis	18	12	5	10
DeKalb	16	10	0	0
Pioneer	14	8	6	12
Zeneca	16	10	0	0
AgrEvo	8	5	2	4
Mycogen	8	5	0	0
CEFOBI	6	4	0	0
Braskalb M.	0	0	8	16
Agroceres M.	0	0	5	10
Germinal	0	0	3	6
CNPSo/EMBRAPA	0	0	2	4
COPERSUCAR	0	0	2	4
Total	153	100	51	100

Source: Banchero et al. (1999).

5 CONCLUSION

Although biotechnology-related research and other supporting activities began relatively early in the LAC region, it is clear that they have not evolved as expected, particularly as regards the commercial exploitation of biotechnologies. Apart from comparatively simple techniques, such as diagnostics and micropropagation, most activities at the commercial level are linked to the importation and release of technologies developed by multinational companies. Several factors have contributed to this situation.

First, agricultural research systems in the region are fragmented. Agricultural research institutes in LAC have developed independently of universities and basic research institutions, a trend that perhaps did not have negative consequences for traditional R&D, but that clearly was not helpful for exploiting advances in molecular biology. Biotechnology requires a much greater interdisciplinary scope and a closer interaction between basic and applied research. Similarly, research institutions are not used to working with the private sector, a factor that has further limited the ability to take the few technologies that have been developed to market.

Second, and probably more importantly, research priorities and levels of investment in Latin America are currently following essentially the same pattern as that of developed countries. Some of the new developments will probably "trickle down" to commercial agriculture in the developing world. This is already happening in some cases, such as transgenic soybeans in Argentina. But the benefits to the rest of LAC agriculture, and particularly to small and resource-poor farmers, will be marginal and incidental. This trend is unsurprising given that the bulk of research investment comes from private sector sources in the developed world.

But the most serious issue is not the direction of investments in developed countries: it is the low level of research and development taking place within Latin America itself. As was shown, the number of people working on biotechnology-related projects is very small when compared to what is happening in other parts of the world. One simple indicator says a great deal about the inadequacy of biotechnology investment in Latin America: one multinational company, Monsanto, employs in its laboratories more than twice the number of biotechnology scientists in the whole LAC region. This is probably the most significant constraint to effectively exploiting the benefits that biotechnology holds for agricultural development in Latin America and the Caribbean. Unfortunately, there are no signs that this situation will change any time soon, since the biotech sector simply reflects current overall trends in regional R&D investments.

LAC countries not only have a serious agricultural R&D underinvestment problem, but also one of abnormally high year to year fluctuations in research budgets. In 1995, LAC countries invested less than 0.45 percent of their agricultural gross domestic product, a level only about one-tenth of what is invested in Australia, about one-sixth of that in Israel, and one-fifth of Canada's relative outlay for agricultural R&D. Between the early 1980s and the early 1990s, investments in the region fell by 10 percent in real terms. In 1992/3, investments in research were estimated at US $588 million (current value); that figure grew to about $1 billion in 1997, only to go back down to less than $640 million in 1998/99 (Mateo et al., 1999).[6] Brazil and Argentina account for almost 75 percent of total investments, and if Colombia, Peru, and Venezuela are added, the figure grows to more than 86 percent. On average, over 85 percent of the budgets go to researchers' salaries, which makes it almost impossible to manage an effective research program. There is clearly a danger of a mounting technological gap between the LAC region and other parts of the world, the effects of which can already be observed in different productivity indicators (cf. Ardila, 1999).

At present there are no signs that this situation will reverse any time soon. Fiscal adjustment programs are still ongoing in full force, putting ever-stricter caps on public budgets for research and the private sector. As we mentioned above, a number of externally funded initiatives (IDB, World

[6] These figures exclude Mexico.

Bank) are setting the stage for a closer cooperation between the research community and the private sector in the form of R&D joint ventures, but given the task they are relatively small, and there are no venture capital mechanisms to help diffuse and speed up these initiatives.

Institutionally, the growing politicization of the biosafety protocol discussions in the context of the Biodiversity Convention and the current situation of biotechnology consumer acceptance in Europe have not yet had any clear implications for either the regulatory environment or for investment and program development. However, the issue is slowly being incorporated into the agenda, particularly in countries like Argentina and Brazil, which are significant players in international agricultural trade. How this will specifically affect future developments in the field is still an open question, but it is clear that research-funding limitations in the LAC region will become worse if there is a perception that biotechnology-derived products are going to encounter more market access restrictions.

REFERENCES

Ardila, J.Y. (1999): Escenarios Para la Agricultura de América Latina y el Caribe: Una Aproximación Desde la Perspectiva del Cambio Técnico. Paper presented at the executive committee meeting, 22-23 April, Interamerican Institute for Cooperation on Agriculture, San José.

Banchero, C., C. Correa, and S. Bergel (1999): Difusión de la Biotecnología en Argentina y Brasil: El Caso de las Plantas Transgénicas. Argentina-Brazil Seminar, 10-11 June 1999, Rio de Janeiro.

FAO (1998): REDBIO '98. III Encuentro Latinoamericano de Biotecnología Vegetal. Food and Agriculture Organization of the United Nations, La Habana.

IICA (1992): Formulación de Políticas para el Desarrollo de la Biotecnología en América Latina y el Caribe. Programa II Generación y Transferencia de Tecnología. Interamerican Institute for Cooperation on Agriculture, San José.

IICA (1993): Requerimientos Técnicos para la Investigación y Desarrollo en Agrobiotecnologías. Serie de Publicaciones Misceláneas, Interamerican Institute for Cooperation on Agriculture, San José.

Jaffé, W., and D. Infante (1996): *Oportunidades y Desafíos de la Biotecnología para la Agricultura y Agroindustria de América Latina y el Caribe.* Interamerican Development Bank, Washington, D.C.

Jaffé, W., and J. van Wijk (1995): *The Impact of Pant Breeders' Rights in Developing Countries*. Directorate General for Development Cooperation, The Hague.

Jaffé, W. (1993): *La Agrobiotecnología Comercial en América Latina y el Caribe.* Interamerican Institute for Cooperation on Agriculture, San José.

Jaffé, W., and M.E. Zaldívar (1993): The Development of Agricultural R&D Capabilities in Latin America and the Caribbean: A Bibliometric Study. Mimeo. Interamerican Institute for Cooperation on Agriculture, San José.

Mateo, N., E. Alarcón, J.Y. Ardila, and E. Moscardi (1999): La Investigación Agropecuaria en América Latina y el Caribe (ALC) y la Paradoja de su Financiamiento. Preliminary paper prepared for the roundtable "Hacia una Mejor Utilización de la Infraestructura Institucional del ALC, en Apoyo a la Investigación y Desarrollo Tecnológico Agropecuario", 2-3 September, Montevideo.

PROCISUR (1997): Subprograma Biotecnología. Documento Marco (Preliminary Version). Science and Technology Cabinet of the Republic of Argentina, Buenos Aires.

Roca, W.M., M.C.Y. Amezquita, V.M. Villalobos (1998): Present Status and Prospects for Agricultural Biotechnology in Latin America and the Caribbean. In: CIAT. *Temas Prioritarios y Mecanismos de Coopración en Investigación Agropecuaria en América Latina y el Caribe*. International Center for Tropical Agriculture, Cali.

Villalobos, V.M (1997): *Current Status and Future Prospects of Modern Biotechnologies in Latin America and the Caribbean*. Food and Agriculture Organization of the United Nations, Rome.

Chapter 6

THE CURRENT AND FUTURE SITUATION OF AGRICULTURAL BIOTECHNOLOGY IN AFRICA: CHALLENGES AND OPPORTUNITIES

Florence Wambugu

Abstract: Currently, African agricultural production is both unsustainable and low. Yields are far below global averages and famine often threatens an ever-increasing population. In addition to deficient agricultural research investments, inappropriate technology delivery systems are responsible for the limited rate of innovation in African small-scale farming systems. Tissue culture and transgenic biotechnologies have great potential to improve the situation and to impact Africa's food security and socioeconomic crisis. Because local research capacities are still underdeveloped, suitable biotechnologies have to be imported from abroad. This requires strengthened North-South, South-South, and public-private sector partnerships. Different ongoing projects with the International Service for the Acquisition of Agri-biotech Applications (ISAAA) and other organizations demonstrate that if biotechnology products are properly introduced in Africa, resource-poor farmers will likely be the main beneficiaries.

1 INTRODUCTION

Improving and increasing the production of food and cash crops in Africa by transferring modern biotechnology applications requires confronting considerable challenges, especially if the aim is to help resource-poor small-scale farmers, who are the largest part of the African agricultural community. These challenges include investments in educating and training personnel to work with the National Biosafety Regulatory Agencies (NBRA), or in the infrastructure needed to develop transgenic crop biotechnologies and related products, which would easily run into the billions of dollars. In the developed world, the high costs of research and development (R&D) are mostly borne by private sector biotechnology

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companies whose enormous investments have produced very promising products, some of which are currently in the market. But such sums are beyond the reach of most African countries, and so R&D is limited or non-existent. Furthermore, African countries have not pursued the potential of private-sector transfers of agricultural biotechnology applications to small-scale farmers.

Such agricultural biotechnology options, however, are available and their impacts can be great. It is not necessary to focus attention solely on highly sophisticated biotechnology applications to obtain results. Often, relatively low key technologies, such as tissue culture, can produce dramatic benefits in the short run while they lay the foundation for other promising and more sophisticated innovations in the long run. But despite such potential, inadequate transportation networks for the so-called "invisible markets" of small-scale farmers limit the private sector's interest and investments. The International Service for the Acquisition of Agri-biotech Applications (ISAAA), with its institutional comparative advantages, has worked to transform these challenges into opportunities by creating public-private partnerships that spur development, provide farmers with appropriate biotechnology and make a positive impact on agriculture and the environment (ISAAA, 1996; FAO, 1991). This paper briefly considers the potential of agricultural biotechnologies in Africa, the challenge of introducing them to resource-poor farmers, and ISAAA's experience with them in its transfer projects.

2 THE POTENTIAL OF BIOTECHNOLOGY FOR AFRICA

Africa's small-scale farmers make up about 80 percent of the farming community and produce 90 percent of all basic food. In general, they grow crops to meet family needs and to produce a modest surplus for investment in future development. On average, these farmers work on a small piece of land (about 5 hectares), take minimal risks by planting many different crops on the same piece of land, have very limited capacity to make capital investments, possess limited formal education and adhere to proven cultural practices. Consequently, unless new technologies are strategically introduced and convincingly demonstrated, farmers are slow to adapt to them. To succeed, the introduction of new biotechnological initiatives and products must be followed up by careful technology transfer monitoring, socioeconomic impact studies and frequent evaluations to identify and alleviate constraints in the technology's diffusion. These new technologies and products should also be introduced to African farmers through proper biosafety regulatory channels so that risk assessments and field evaluations can be performed to analyze the appropriateness and suitability of particular applications for Africa's agriculture and environment (Krattiger and Rosemarin, 1994).

Currently, African agricultural production is both unsustainable and low. Yields are far below global averages and famine often threatens an ever-increasing population. People farm more, but without the necessary inputs to restore soil fertility and improve yields. In addition, farms expand into ecologically sensitive marginal lands, putting even more pressure on the region's limited natural resources. The search for farmland, the establishment of temporary settlements and the consumption of wood for fuel and cooking – which 80 percent of the rural population depends upon – causes biodiversity losses, soil erosion, river pollution and the destruction of natural forests. As farms encroach upon game-parks, they also adversely affect wildlife, which is an environmental and economic problem since these parks generate considerable income for some African countries through tourism. These problems are compounded by low capital investments in agricultural improvements (especially for food crops), the limited utilization of agricultural technology and products such as improved seeds and an unstable political climate that hardly attracts long-term foreign investors.

Yet ISAAA's experience in Africa has shown that new agricultural biotechnologies and products can have a tremendous, positive impact on sustainable agricultural development that protects the environment. Results from ISAAA's current initiatives indicate that biotechnology enhances food security, helps create stable, progressive agriculture-based communities, reduces urban migration and increases political stability. The evidence shows that these new technologies dramatically improve yields by increasing crop production per unit of land. This alleviates the need to encroach on forests and to farm in unfit marginal lands, both of which are leading causes of topsoil erosion and biodiversity destruction (Thottapilly et al., 1992).

3 CURRENT BIOTECHNOLOGY INITIATIVES AND FUTURE CHALLENGES

Globally, 27.8 million hectares were cultivated with genetically modified crops in 1998, a number that rapidly increased to 39.9 million hectares in 1999 (James, 1999; James, 1998). The technology is having a major and growing impact, but only a very small area of the millions of hectares devoted to genetically modified crops was grown in Africa. South Africa is commercially growing *Bacillus thuringiensis* (*Bt*) cotton and maize. Egypt is field-testing transgenic technology to control the potato tuber moth (for this project traditional North-South partnerships existed, and guidelines were in place for biosafety, intellectual property rights (IPRs) and product development). In 2000, Kenya will test transgenic sweetpotato protected against sweetpotato feathery mottle virus (SPFMV) through coat protein gene technology, and Mauritius has developed transgenic herbicide-tolerant sugarcane. Zimbabwe will soon acquire some transgenic technologies from South Africa. The rest of Africa is hoping that the biotechnology revolution will not pass them by, as the green revolution did, due to a lack of resources and unrealistic, controversial arguments from Europe based on socioeconomic issues.

What makes biotechnology even more attractive for resource-poor African farmers, most of whom cannot even read or write, is the technology's delivery system. It is packaged in the seed, and so farmers do not have to change their cultural practices or provide high-level inputs to benefit. The previous high-input technology models lately introduced, mainly by donors as agricultural aid, have failed to impact Africa because they require farmers to change their cultural practices. Improved transgenic seeds do not. Furthermore, farmers have a positive view of improved seed products because they have benefited from the increased quality and productivity of widely used maize hybrid varieties.

For vegetatively propagated crops, a more recent success story has been the introduction of tissue culture (TC) banana biotechnology in Kenya. A project of the Kenya Agricultural Research Institute (KARI) and ISAAA, it proves beyond any doubt that African farmers can adopt and benefit from new technologies with great speed and impact. Both small- and large-scale farmers are already using TC banana technology, and their experience with it has also provided the involved organizations with insights into improving product development and distribution, delivery systems and commercialization strategies. An independent socioeconomic impact study of TC banana technology was carried out in Kenya, and it clearly indicates that small-scale farmers could accrue higher benefits than medium- and large-scale farmers (Qaim, 1999a). These insights will be adopted to meet the challenges of delivering the technology to an even larger number of small-scale farmers.

Furthermore, transgenic banana technologies that protect against the devastating banana disease known as "sigatoka leaf spot" are in the pipeline, having been developed by such international centers as the International Network for the Improvement of Banana and Plantain (INIBAP) in France and the International Institute of Tropical Agriculture (IITA) in Nigeria. The transfer and delivery of transgenic banana technology will greatly benefit from the TC experience in Kenya and other African countries.

Another example of a successful recombinant crop technology in Africa is the forthcoming introduction, field evaluation, and commercialization of transgenic sweetpotatoes with coat protein mediated virus resistance. Transgenic field trials in Kenya are expected to take place in 2000 following the approval of a permit application submitted to the Kenya National Biosafety Committee (KNBC) in late 1999. Sweetpotato is a food crop for the majority of subsistent small-scale farmers in Africa, but viral diseases cause considerable yield losses for the crop, and the cultural control practices that have been put in place are unfortunately relatively ineffective.

Developed by KARI scientists working from 1992 to 1998 at Monsanto in the USA, this gene technology solution is considered the only viable long-term approach to controlling SPFMV disease. The North-South (USA-Kenya), private-public (Monsanto-KARI) partnership was partly funded by the United States Agency for International Development (USAID), and Monsanto donated the technology free of royalty payments for use in Kenya and other African countries. ISAAA is brokering and facilitating the technology transfer to KARI. The field evaluation, distribution and commercialization of the transgenic sweetpotatoes will benefit from the knowledge gained in the TC banana biotechnology project. Overall, the technology is expected to make a positive impact on national food security (Wambugu, 1994). The potential socioeconomic implications of transgenic sweetpotatoes have also been independently scrutinized, and the results show that small-scale farmers are likely to become the main beneficiaries (Qaim, 1999b).

The sweetpotato biotechnology has no intrinsic foodsafety issues. The coat protein gene has already been deregulated in the USA and elsewhere. In fact, it was one of the first biotechnology applications approved for commercial use. The foodsafety analysis in Kenya will be handled according to the UN's Food and Agriculture Organization (FAO) guidelines for "substantive equivalent studies". Environmental safety issues will be evaluated during the field trials in Kenya.

Controlling SPFMV could double sweetpotato yields, but assuming conservatively that the technology produces only a 15 percent average increase in yield, then the total gain from the improved sweetpotatoes would be 1.8 million tons per year. The value of sweetpotatoes grown by subsistence growers in Africa is about US $275 per ton, and so virus-resistant sweetpotatoes could potentially be worth an additional US $495 million to African farmers per year. More importantly, the extra 1.8 million tons would supply half the dietary needs of about 10 million people, with no additional production costs or inputs.

4 CONCLUSION

To summarize the current status and future promise of biotechnology in Africa:

- Both tissue culture and transgenic biotechnologies have great potential to impact Africa's food security and socioeconomic crisis.
- Africa lacks the high capital infrastructure and capacity required to develop transgenic technology. It will therefore depend primarily on collaborations based on North-South, South-South, and public-private partnerships to deploy agricultural biotechnology. Too strict and overly preventive international laws (e.g., a biosafety protocol solely based on precautionary principles) could discourage biotechnology transfer, which clearly would be to Africa's disadvantage.
- African scientists and policy-makers need to be open-minded in acquiring, adapting, and testing beneficial biotechnologies appropriate for their countries. They need to be weary of the persuasive critics of biotechnology from Europe who advise that Africa should be excluded from biotechnology.
- African countries first need to establish the necessary infrastructures and capacities that will enhance R&D on strategic biotechnology applications and that will encourage the transfer of biotechnology applications for Africa's benefit.

REFERENCES

FAO (1991): Biotechnology as a Means for Improving Agricultural Production in Kenya; An Experts Report and Proposed Plan of Action. In: A.M. Mailu, J.O. Mugah, and P.O. Fungoh (eds.). *Proceedings of the National Conference on Plant and Animal Biotechnology*. Kenya Agricultural Research Institute, Nairobi, pp. 271-286.

ISAAA (1996): *ISAAA Annual Report 1995; Shared Solutions to Shared Problems*. International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

James, C. (1999): Global Status of Commercialized Transgenic Crops: 1999. ISAAA Briefs, No. 12, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

James, C. (1998): Global Review of Commercialized Transgenic Crops: 1998. ISAAA Briefs, No. 8, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

Krattiger, A.F., and A. Rosemarin. (eds.) (1994): *Biosafety for Sustainable Agriculture; Sharing Biotechnology Regulatory Experiences of the Western Hemisphere*. International Service for the Acquisition of Agri-biotech Applications, Stockholm Environment Institute, Ithaca, NY and Stockholm.

Qaim, M. (1999a): Assessing the Impact of Banana Biotechnology in Kenya. ISAAA Briefs, No. 10, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

Qaim, M. (1999b): The Economic Effects of Genetically Modified Orphan Commodities: Projections for Sweetpotato in Kenya. ISAAA Briefs, No. 13, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

Thottapilly, G., L. Monti, D.R. Mohan Raj, and A.W. Moore. (eds.) (1992): *Biotechnology: Enhancing Research on Tropical Crops in Africa*. International Institute for Tropical Agriculture, Ibadan, Nigeria.

Wambugu, F.M. (1994): Three Year External and Internal Review: African Sweet Potato Virus Diseases Control and Biotechnology Transfer Project. Monsanto, United States Agency for International Development, University of Michigan, and University of Columbia Missouri, document available from Monsanto Company, Plant Science Department, St. Louis.

Chapter 7

BIOTECHNOLOGY RESEARCH IN RICE FOR ASIA: PRIORITIES, FOCUS AND DIRECTIONS

Mahabub Hossain, John Bennett, Swapan Datta, Hei Leung, and Gurdev Khush

Abstract: Over the last four decades, substantial genetic improvements have been made in rice through conventional breeding. The adoption of modern rice varieties by farmers in irrigated ecosystems has contributed to food production increases that were greater than the growth in population. The "green revolution" in rice cultivation, however, has bypassed unfavorable rice-growing environments that still account for over half of the rice land. These areas are subject to droughts, floods and problem soils that have been difficult to handle through conventional breeding. Biotechnology research has opened up new opportunities to address agricultural problems in unfavorable environments, where the majority of Asia's poor now live. Current research on rice biotechnology, however, focuses more on insect and disease resistance than on stresses faced by farmers in less favored lands. For biotechnology to benefit the poor, research directions must be changed and their output widely shared.

1 INTRODUCTION

Because of its hot and humid climate that so favorably suits rice cultivation, Asia accounts for 90 percent of the world's production and consumption of rice. In humid and sub-humid Asia, rice is the principal staple food, providing 50-80 percent of the calories consumed by the people. It is also the single most important source of employment and incomes for the rural people (Hossain and Fischer, 1995; Hossain, 1988). Numerous tiny farms grow rice primarily for family needs. In countries with a per capita income of US $500 or less, rice accounts for one-third to one-half of the value added, and one-fifth to one-third of the gross domestic product. Since rice is more important to the economy and people at lower income levels, it

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is a crucial intervention point for efforts to promote agricultural development and poverty alleviation in Asia.

Despite the closing down of the land frontier in most countries, Asia has done remarkably well in meeting the food needs of the people. The phenomenal increase in agricultural productivity made possible by the research of the "green revolution" allowed Asia to avoid dire predictions of severe food insecurity and famine (Paddock and Paddock, 1967; Brown, 1974; Eckholm, 1976). Food production actually outpaced population growth, and the prices of rice adjusted for inflation fell, which significantly contributed to poverty alleviation (Hossain and Pingali, 1998; David and Otsuka, 1994).

But much remains to be done. Nearly 700 million of the world's 1.2 billion poor people live in Asia – nearly 400 million of them in India and Bangladesh. Most of the countries in South and Southeast Asia have a daily per capita energy intake of less than 2,400 kilocalories. The incidence of child malnutrition is higher in South Asia than in Sub-Saharan Africa (UNDP, 1998). There are also doubts about whether a "new doubly green revolution", one that is environmentally sustainable as well as yield increasing, can meet the food needs of low-income countries that will not reach a stationary population until the end of the next century (Conway, 1998).

Maintaining an adequate supply of rice in the face of a continued population explosion in low-income, poverty-stricken regions is a formidable challenge for Asia. Scientific advancements in molecular biology and its use in genetically enhancing staple food crops are considered the most significant developments in the entire history of plant breeding. Genomics, the deciphering of sequences and their functional relationships in the total genome, has been the engine for gene discoveries that can ultimately lead to incorporating useful traits in plants. This biotechnology revolution is very relevant to the problems of food security, poverty reduction, and environmental conservation in the developing world, including Asia. But for many it raises important questions relating to ethics, biosafety and intellectual property rights (cf. Serageldin, 1999).

This paper attempts to provide a forum for discussing biotechnology's role in rice research. Section 2 reviews the achievements and limitations of conventional plant breeding approaches to genetically enhance rice. Available biotechnology tools are reviewed in section 3, and the priorities for their use are discussed in section 4. Recent advances in rice biotechnology research and their directions are reviewed in section 5. Section 6 concludes the paper with some observations on reaching the poor with the fruits of biotechnology research.

2 THE ACHIEVEMENTS AND LIMITATIONS OF CONVENTIONAL RICE BREEDING

2.1 Technological Progress

The dramatic achievements in the world rice economy over the last quarter century were largely due to genetic enhancements in rices. These were made possible through the joint efforts of rice researchers in the national systems and scientists at the International Rice Research Institute (IRRI). Before the advent of the green revolution, rice varieties were tall and leafy with a grain biomass ratio of 3:7 and a harvest index of 0.3 (i.e., the ratio of grain to the total biological yield of the crop). To increase the yield potential it was necessary to promote nitrogen responsiveness in rice plants by developing lodging resistance. This was accomplished by reducing the plant height through incorporating a resistance gene for short stature (sd-1) from a Chinese variety, Dee-geo-woo-gen (Khush, 1995). In 1966, scientists developed a semi-dwarf variety with sturdy stems (IR8) that quickly became popular with farmers and initiated the green revolution in rice cultivation in Asia. It had a harvest index of 0.5, and with optimum crop management doubled the yield potential of traditional varieties. Being photoperiod-insensitive it could be planted at any time of the year, making the rice crop well suited for any cropping system that farmers would find profitable. This land-saving technological innovation enabled farmers to increase food production without extending cultivation onto marginal land. But it also increased farmers' dependence on chemical fertilizers and required water control in rice farms. Supplementary investments were needed to develop irrigation facilities. And in the early stage, before genetic resistance to pests was built in with the new cultivars, farmers had to rely on insecticides for pest management.

Rice scientists then shifted their attention to developing high-yielding varieties with shorter growth duration. Most traditional varieties in tropical and subtropical Asia matured in 160-170 days and many were photoperiod sensitive. These were suitable for growing one crop of rice a year during the rainy season. Plant breeders subsequently developed varieties that matured in 100 to 110 days without lowering the yield. The key to success was the selection of genotypes with rapid vegetative vigor in earlier growth stages. This allowed farmers to grow two rice crops per year in areas with good irrigation facilities, or they could grow a non-rice crop in the rice-based system under rainfed conditions. Higher cropping intensity contributed to increased employment of farm workers and to the diversification of agricultural production, since food needs could be met with less land devoted to food grains. In China, Indonesia and Vietnam, farmers now raise nitrogen-fixing legumes in-between two rice crops in intensively cultivated irrigated areas, thereby mitigating the problem of sustainable intensive farming.

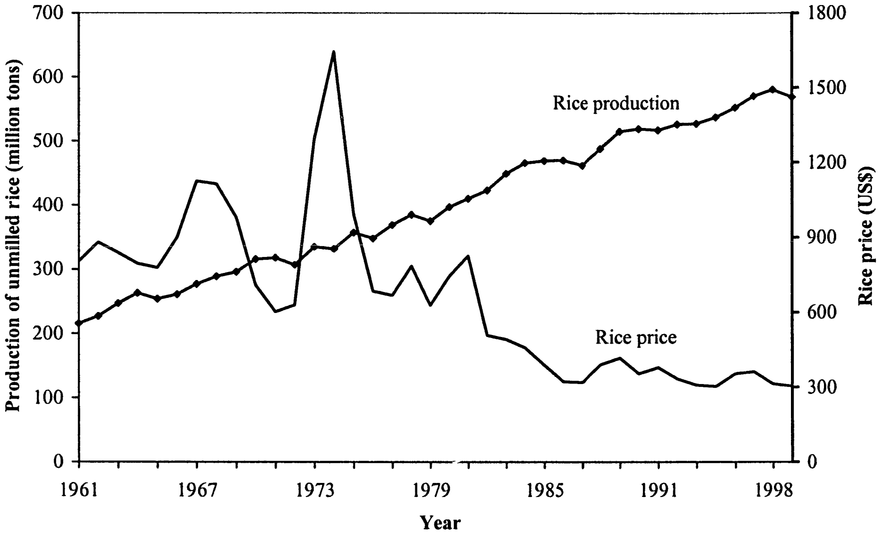
As the profitability of rice farming increased with new varieties, a relatively small number of improved varieties have replaced thousands of traditional ones, which reduced the crop's genetic variability. The reduction in biodiversity, coupled with vegetative growth and continuous cropping, increased the vulnerability of rice to insects and diseases. Scientists addressed this problem by incorporating resistance to major insects and diseases in newly released modern varieties. Large germplasm collections were screened and donor lines for resistance identified. Utilizing these donors, improved varieties with resistance to four major diseases (blast, bacterial blight, sheath blight, and tungro) and four insects (brown planthopper, green leafhopper, gall midge, and stem borers) have been developed. These varieties have as many as 20 different parents in their ancestry. The adoption of varieties with a broader genetic base has helped to stabilize rice yields and reduce the consumption of pesticides which are known to have serious adverse effects on human health and on water quality (Rola and Pingali, 1993).

Nutritional deficiencies and soil toxicities constrain the expansion of rice cultivation to some areas otherwise suitable for the crop. Intensive rice cultivation and the unbalanced use of chemical fertilizers can lead to micronutrient deficiencies in the soil. For example, zinc and sulfur deficiency in rice soils is becoming a major concern in many countries. Furthermore, large tracts of rice soils in coastal areas and in regions where ground water is used for irrigation have different levels of salinity and alkalinity. Breeders have been addressing this problem by developing modern varieties with moderate to high levels of tolerance for a number of nutritional deficiencies and toxicities. So far, however, only limited success has been achieved.

2.2 Impact on Food Security and Poverty Alleviation

Technological progress has contributed to poverty alleviation mainly by inducing a decline in the real prices of food grains. Because cereal grains are basic necessities, the price declines disproportionately when supply increases faster than demand. Therefore, the gains from technological progress (higher efficiency in the use of inputs and lower unit costs) are quickly passed on from producers to consumers in the form of lower prices. As rice production increased faster than population growth, the price of rice adjusted for inflation declined by nearly 40 percent over the last 30 years (see Figure 1).

Figure 1: Trends in world rice production and prices (1961-98)



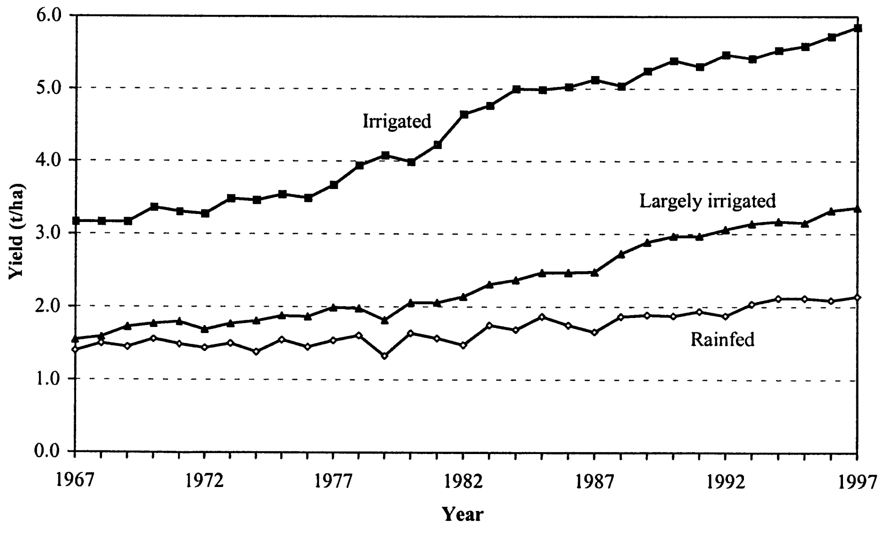
Note: The rice price relates to Thai rice 5 percent broken, deflated by G-5 MUV Index deflator.
Sources: FAO (1999), World Bank (various issues).

The decline in relative prices has benefited the urban laboring class and the rural landless much more than the upper income groups, because the former spend a much larger proportion of their incomes on food grains than the latter. As net consumers of rice, small and marginal producers, who are the dominant group of farmers in land-scarce countries, also gained from both lower prices and declines in the unit cost of production. Technological progress in food grain production has also benefited the poor by creating more jobs and pushing up wage rates (Hossain, 1988; David and Otsuka, 1994; Hazell and Ramasamy, 1991). Modern varieties require more labor per unit of land because more intensive care and intercultural operations are needed for the crop. Furthermore, the greater intensity in cropping made possible by reducing the crop's growth time has increased employment opportunities in crop production throughout the year. Because staple food grains are the dominant crops for low-income people, productivity increases contribute substantially to the growth of agricultural incomes. Employment is also generated in the processing and marketing of additional agricultural output, in trade and transport services arising from higher purchases of non-farm goods and services, in construction activities for housing improvements, and so on.

But only irrigated and favorable rainfed ecosystems have been able to adopt the technological innovations and to benefit from their favorable impact on productivity growth, employment and incomes. Large parts of Asia, particularly the uplands and rainfed lowlands, have yet to benefit from green-revolution technologies because scientists have had limited success in developing appropriate high-yielding rices that can adapt to the floods, droughts, temporary submergence, strong winds and problem soils that characterize these ecosystems. Available modern varieties may do well in normal years but perform poorly compared to traditional varieties if there is a prolonged drought or sudden submergence of the plant due to the vagaries of a monsoon. Accordingly, farmers grow modern varieties where there are good irrigation and drainage facilities, or where the rainfall is certain and evenly distributed throughout the growing season. If rainfall is unreliable and the cultivation risk is high, then farmers will grow traditional varieties and use fertilizer in small amounts.

The lack of time series data does not permit us to review the trend in rice production by ecosystems. We have, however, classified the rice-growing countries and regions (the states, provinces and districts of India, China, Indonesia and Bangladesh) into three groups: irrigated (over 90 percent of the riceland irrigated), largely irrigated (40 to 90 percent irrigated), and rainfed (less than 40 percent irrigated). We then estimated the increase in rice yields. The results may be reviewed in Figure 2, which shows that the green revolution has largely benefited the irrigated regions that already had high yields before the green revolution. The yield has increased from 3.2

Figure 2: Trends in rice yields for irrigated and rainfed ecosystems (1967-97)



Sources: IRRI World Rice Statistics, and FAO (1999).

tons per hectare during 1967-69 to 5.7 tons per hectare during 1995-97. Yield increases are lowest in rainfed regions, which have only increased from 1.5 to 2.1 tons per hectare during the thirty-year period. Rainfed regions still account for nearly 40 percent of the rice cropped area in Asia. These are the regions where poverty and food insecurity are still widespread and where the demand for rice is growing fast due to high population growth and positive income elasticities of the demand for food. If biotechnology research is to make any impact on the poor, researchers must focus on addressing the problems of these unfavorable rice-growing regions.

3 BIOTECHNOLOGY TOOLS

Rice has the smallest genome of all cereals, and within a short period it will be the first agriculturally relevant crop species completely sequenced by public research institutions. The following are some downstream approaches based on this research that will be used to incorporate and improve useful traits in the rice plant.

Functional genomics. As the rice genome is completely sequenced, biotechnologists are systematically assessing the phenotypes resulting from the disruption of putative gene sequences with genetic resources such as mutants, near-isogenic lines, permanent mapping populations, and elite and conserved germplasm. To a large extent, functional genomics is analogous to the extensive germplasm screening that has allowed conventional breeding programs to extract useful traits. Sequencing provides DNA level precision on a global genome scale. Near-isogenic introgression lines are being developed to capture diverse alleles from the germplasm pool. A large collection of chemical and irradiation-induced mutants are also being produced for forward and reverse genetics that can be used in extensive phenotype screening. These materials are at different stages of development and are available as public goods. With these genetic resources, research on functional genomics can help evaluate agronomic characters to produce a rich phenotype bank with direct links to sequence information, which will facilitate plant breeding.

Genetic engineering. This involves cloning and incorporating single or multiple genes through transformation to modify the rice plant for improvement. Protocols for rice transformation have been developed that transfer foreign genes from diverse biological systems into rice. Direct DNA transfer methods, such as protoplasts (Datta et al., 1990), biolistic (Christou et al., 1991), and *Agrobacterium*-mediated (Hiei et al., 1994), are routinely used to transform rice at biotechnology laboratories in IRRI and other advanced institutions in Japan, South Korea, China, India and Singapore.

Traditionally, the introduced genes are selected using an antibiotic selection marker. New options, however, use non-antibiotic selection methods or evict the antibiotic selection marker. These new approaches, if successful, will remove major concerns about foodsafety associated with transgenic plants.

Marker-assisted breeding (MAS). This involves the use of molecular markers to track traits of interest and to effectively combine multiple genes. Molecular markers have made it possible to map and tag quantitative trait loci (QTL) that affect characters such as yield, quality and tolerance to abiotic stresses. Traditional breeding and backcrossing require extensive phenotypic selection; MAS is faster, more accurate, and more efficient in backcrossing populations, which can be screened at early seedling stages and under various environmental conditions. MAS is a timesaving and accurate method to pyramid genes in a variety. The successful use of this technique has been reported in the pyramiding of four *Xa*-genes for bacterial blight resistance (Huang et al. 1997). The pyramided line usually has more durable resistance than the one with a single gene, and the former can be used as a donor for transferring resistance genes into other desirable cultivars. Unlike approaches that involve genetic modification through transformation, MAS has been considered an uncontroversial and 'benign' biotechnology. For this reason, MAS is now widely practiced in Asian laboratories, and in many cases it is well integrated into the rice-breeding program. The effectiveness of MAS depends upon how accurately a marker predicts the contribution of a gene to a desirable trait. In the case of many quantitative traits, the effectiveness of MAS is yet to be proven.

4 PRIORITY AREAS FOR APPLICATION

Given both the achievements and limitations of conventional plant breeding for rice improvement and the needs of unfavorable rice-growing environments (marginal land), the following should be the ideal priority areas for biotechnology research in rice.

Tolerance to abiotic stresses. The inheritance of adaptability traits, such as drought, submergence, elongation ability and tolerance for mineral stresses, is not yet adequately understood. Very little information is available on the rice plant's tolerance mechanisms for these traits (Khush, 1995). Functional genomics can generate this information for plant breeders, and both gene mapping and MAS can aid efforts to develop high-yielding rices with tolerance to these stresses (many traditional cultivars have acquired these traits through centuries of evolution, but they have very low yields). These traits are governed by a collection of minor genes (Bennett, 1995). Although mapping studies of minor genes or QTL are more difficult than those of major genes, over the long-term MAS could be a more effective strategy given conventional plant breeding's lack of success in addressing these problems. IRRI has already developed several salinity-tolerant rice lines through anther culture, which could be further improved through transformation.

Research on abiotic stress tolerance provides many excellent opportunities for collaboration among advanced research institutes in developed countries (ARIs), IRRI, and national agricultural research systems (NARSs). The ARIs can focus on several issues:

- identifying the physiological and molecular basis of the various mechanisms of stress tolerance already available in rice germplasm,
- studying model systems, such as yeast and *Arabidopsis*, at the genomic and proteomic levels, and
- developing tools for applying similar analyses to tolerant and susceptible rice cultivars grown under field conditions at IRRI and at NARSs and under controlled conditions in IRRI's Phytotron and glass houses.

The focus at IRRI and NARSs will be on developing germplasm (contrasting cultivars, segregating populations, near isogenic introgression lines and mutants) to which the genomic and proteomic tools will be applied under both controlled and field conditions. The outputs of the research will include:

- new cultivars with stress tolerance enhanced by the combination of diverse mechanisms and the combination of tolerances to multiple stresses,
- isolated genes suitable for use in transformation, and
- transgenic rice with novel stress tolerance mechanisms derived from other organisms.

Durable host-plant resistance. Host plant resistance is the cornerstone of effective pest management. Combining varietal resistance with biological agents and cultural practices can reduce the use of harmful agro-chemicals. Biotechnology tools enable the characterization of insects and pathogen population structures that can guide the deployment of pest-resistant cultivars. Over the years, many rice varieties have been developed with multiple resistance to insects and diseases. But resistant varieties do not remain resistant forever; pathogen populations adapt and breakdown resistance. For major pest problems, it would be worthwhile to devise a resistance mechanism using cloned genes from other sources. For rice, yellow stem borer and sheath blight are targets for this approach. DNA recombinant methods are currently being used to transfer *Bacillus thuringiensis (Bt)* and chitinase genes to enhance resistance (Datta et al., 1998, 2000).

For some pests, it is necessary to combine genes with similar effects to achieve more durable resistance. For example, to combine genes for resistance to blast fungus and bacterial blight, researchers are using gene mapping techniques to locate each resistance gene on a specific chromosome of rice and to identify flanking DNA markers for use in marker-assisted selection (Bennett, 1995). Because these pathogens are highly variable in different locations, different combinations of genes are required for wide adaptability of the improved cultivars.

Enhancing nutritional quality. The vast majority of the rural and urban poor in Asia rely heavily on rice for their major source of energy and protein. The average annual per capita intake of rice varies from 100 to 170 kilograms in most low-income countries. Consumers at low-income levels cannot afford to diversify their diets and improve their nutritional intake. As a result, micronutrient-induced malnutrition is widely prevalent in Asia. Vitamin A deficiency affects some 400 million people worldwide, leaving them vulnerable to infections and blindness. Iron deficiency affects 3.7 billion people, particularly women, leading to high maternal deaths and infant mortality. Developing micronutrient dense rices, with higher amounts of iron, zinc and vitamin A, can have a tremendous impact on the health of low-income people (Underwood, 1999). Conventional breeding when combined with biotechnology can provide very powerful tools to achieve this goal (for more details, see Howarth Bouis' paper in this book).

Nitrogen fixation in rice. Cultivating modern rice varieties requires applications of nitrogen fertilizer in large amounts, an input that is often beyond the reach of marginal and small farmers. Nitrogen use efficiency in rice is low, and nitrogen losses cause environmental problems. Biotechnology can be used to genetically manipulate the rice plant and associated bacteria to create either (i) a tighter interaction between free-living diazotrophs and rice to improve nitrogen use efficiency or (ii) a nodule-like structure in rice to harbor nitrogen fixing symbionts (Bennett, 1995). If successful, this innovation could make a very useful contribution to reducing farmers' dependence on chemical fertilizers.

Apomixis for hybrid seeds. Rice hybrids have been developed for both temperate and tropical agro-ecoregions that provide 15-20 percent yield advantages over inbred rices (Virmani, 1994). Their adoption by farmers, however, is constrained by the need to purchase seed every season and high seed costs. Apomixis is a method of reproducing seed directly from the ovule without fertilization by pollen. Apomictic hybrid rice could be reproduced by farmers themselves at minimal cost. Studies indicate that the switch from sexual reproduction to apomixis may be controlled by as few as 1-2 genes (Bennett, 1995). Biotechnology could help map and isolate the apomixis genes and transfer them to rice.

Table 1: Priority traits in rice and means of delivery for sustainable food security

			Preference approach		
Priority traits	Target environment	Available product	Conv. breeding	MAS	Trans-genic
Stress tolerance					
Bacterial blight	Rainfed lowland	Genes and markers	++	++++	++++
Sheath blight	Irrigated, high yield	Transgenic lines	+	+	++++
Blast	Upland	Markers	+++	+++	+
Stemborer	All	Transgenic lines	+	0	++++
Drought	Rainfed lowland, upland	Under development	++	+	+
Salinity	Coastal areas		+++	+	++
Nutritional value					
Vitamin A		Gene constr., transg. lines	+	0	++++
Iron			+++	++	+
Zinc			+	0	?
Yield enhancement	All	Elite lines	++++	++	++

To conclude, biotechnology applications should be environmentally focussed, impact oriented and complementary to conventional breeding. Given the private sector's huge investment in biotechnology, researchers in public sector institutions must wisely choose target traits and environments that can substantially impact low-income farmers and consumers. Table 1 cites preferred approaches for addressing different priority traits, and while these are not necessarily complete and may be subject to controversy, they illustrate a strategic approach for setting biotechnology research priorities for rice.

5 BIOTECHNOLOGY RESEARCH ON RICE: FOCUS AND DIRECTIONS

The Rockefeller Foundation has been the driving force behind biotechnology research in rice. Since the mid 1980s, the Foundation has invested more than US $100 million to support biotechnology research on rice in developing and developed countries and on international meetings to exchange and review research findings. IRRI and several NARSs in Asia have been major beneficiaries of this support.

Figure 3 provides a summary of the status of IRRI's biotechnology program as of mid-1999. It covers both transformation and DNA markers and emphasizes the need for the three "Bs": basic research, biotechnology, and breeding.

In order to see the focus and direction in rice biotechnology research, as well as the geographical location of the laboratories where such research was conducted, we sifted through the abstracts of the papers and poster

Figure 3: Status of biotechnology activities at IRRI (mid 1999)

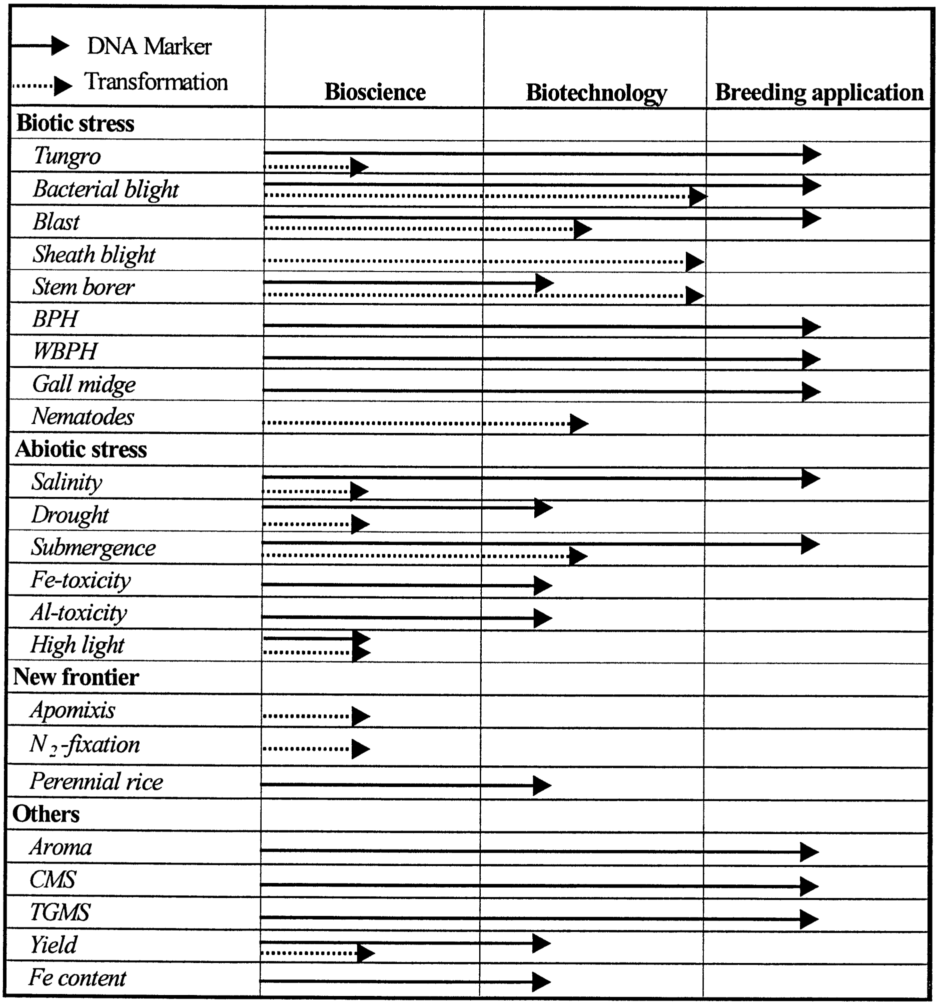


Table 2: Distribution of papers presented in the rice biotechnology meetings of the Rockefeller Foundation, by geographical location of laboratories

	1994 [a]		1997 [b]		1999 [c]	
Geographic location	No. of papers	Percent	No. of papers	Percent	No. of papers	Percent
Developed countries outside Asia	88	40.3	84	29.0	73	23.9
Japan, Korea	14	6.4	21	7.2	32	10.5
China	39	17.9	44	15.2	40	13.1
India	31	14.2	65	22.4	71	23.3
Philippines	22	10.1	31	10.7	40	13.1
Other Asia	24	11.0	45	15.5	45	14.8
Total	218	100.0	290	100.0	301	100.0

a. Papers presented in the meeting held in Bali, Indonesia.
b. Papers presented in the meeting held in Malacca, Malaysia.
c. Papers presented in the meeting held in Phuket, Thailand.

Source: Rockefeller Foundation (1994, 1997, 1999).

presentations of the successive Rice Biotechnology meetings organized by the Rockefeller Foundation since 1994 (Rockefeller Foundation, 1994, 1997, 1999). Findings are reported in Tables 2 and 3. The figures demonstrate that work on biotechnology for rice improvement has been growing substantially over time. The number of scientific presentations in the meetings increased from 218 in 1994 to 301 in 1999.

In the initial years, rice biotechnology research was located in the laboratories of developed countries outside Asia. The focus of the research was mainly upstream, on developing protocols and promoters for gene transformation and on gene mapping and characterization. In most cases, research was done in collaboration with graduate students from Asia. The developed countries' relative contribution to biotechnology research, however, has declined over time. Nearly 40 percent of the research papers contributed to the 1994 Bali meeting were from scientists working in laboratories located in developed countries outside Asia; by 1999, this share had decreased to 24 percent (Table 2).

Within Asia, most of the research papers originated from public sector laboratories in India and China. This is not surprising given that these two Asian giants account for nearly 60 percent of the Asian rice output. But the interest of Indian scientists in biotechnology research is noteworthy considering that a large part of the unfavorable rice-growing environment is located in India. While the output flow from China has declined substantially, India's has been growing rapidly. In both these countries, the major focus of research has remained on developing resistance to insects and

Table 3: Distribution of papers presented in the rice biotechnology meetings of the Rockefeller Foundation, by field of research

Field of research	1994 [a]		1997 [b]		1999 [c]	
	No. of papers	Percent	No. of papers	Percent	No. of papers	Percent
Biotic stresses	86	39.5	108	37.2	116	38.5
Insects	28	12.8	37	12.8	37	12.3
Diseases	58	26.6	71	24.5	79	26.2
Abiotic stresses	20	9.2	25	8.6	35	11.6
Drought	8	3.7	11	3.8	14	4.7
Submergence	5	2.3	7	2.4	8	2.7
Salinity/coldness	7	3.2	7	2.4	13	4.3
Human nutrition	6	2.8	4	1.4	2	0.7
Yield/quality	32	14.7	64	22.1	53	17.6
Transg. methodology	35	16.1	46	15.9	43	14.3
Genomics	39	17.9	43	14.8	54	17.9
Total	218	100.0	290	100.0	301	100.0

a. Papers presented in the meeting held in Bali, Indonesia.
b. Papers presented in the meeting held in Malacca, Malaysia.
c. Papers presented in the meeting held in Phuket, Thailand.

Source: Rockefeller Foundation (1994, 1997, 1999).

diseases, on mapping QTL for yield advancements, and on exploiting heterosis for hybrids. Work on abiotic stresses, however, has remained limited. Only 10 of 71 papers presented by Indian scientists in the Rockefeller Foundation's Rice Biotechnology meetings focused on problems related to drought, submergence or problem soils. Because public sector institutions conduct most of the work, the problem of disseminating biotechnology products to low-income farmers, a concern raised by many non-governmental organizations (NGOs), may not be an issue in rice.

In Japan and Korea, per capita rice consumption has been declining for some time, and they now face the problem of disposing of surplus rice. Still, their investment in rice biotechnology is significant and has been growing fast. The number of papers presented by scientists from these countries increased from 14 in 1994 to 32 in 1999. South Korea joined this effort rather late, initiating a biotechnology research program in 1994. But their research output has expanded rapidly since then. Japan and Korea, where biotechnology research has been conducted primarily in public sector institutions, may use biotechnology to stabilize rice yields and reduce dependence on agrochemicals such as insecticides, fungicides and herbicides. They can also share their biotechnology products with the less developed rice-growing countries of Asia that cannot afford heavy investments in biotechnology facilities.

IRRI and the Philippine Rice Research Institute conduct most of the biotechnology research in the Philippines. Only 13 percent of the papers presented in the Phuket meeting in 1999 were presented by scientists from these institutions. IRRI accounts for only a small share of the Asian biotechnology research, but it plays a catalytic role in promoting downstream biotechnology research in Asia's developing countries by mobilizing financial support and providing training to NARS scientists through the Asian Rice Biotechnology Network (ARBN). Research at IRRI concentrates more on issues related to insects and disease resistance than on abiotic stresses. Only 4 of 40 papers presented in the 1999 Phuket meeting were on issues related to drought, submergence or salinity tolerance.

Asia's biotechnology research infrastructure is limited outside the countries mentioned above. Singapore, Malaysia and Indonesia have some facilities that will probably grow in the future. But most other countries are not expected to have the resources needed to participate in the biotechnology revolution. Whether biotechnology will benefit their farmers and consumers depends on the international transfer of appropriate technologies.

Table 3 presents the general thrust of biotechnology research with respect to the development of useful traits and changing directions. About a third of the papers presented in the biotechnology meetings reported work in the areas of gene mapping, characterization, functional genomics, and transgenic methodology. The focus of research in these upstream areas has declined over the 1994-95 period, albeit only marginally. Two-fifths of the papers reported outputs related to developing resistances against insects and diseases. These are the areas where conventional breeding has also been successful. Advances in this line of research still merely substitute skills that already exist in most Asian countries for developing host plant resistance via conventional breeding. Biotechnology may increase the efficiency of conducting such research and the durability of the product, but work on developing tolerances against drought, submergence and problem soils, areas in which traditional breeding has been less successful, has so far received inadequate attention of rice biotechnologists. Only 12 percent of the papers presented in the 1999 meeting reported work in these areas. Efforts to improve human nutrition have also received limited attention. Clearly, there is a mismatch between the studies that biotechnology researchers are pursuing and the urgent problems facing resource-poor farmers in unfavorable environments.

Some selected achievements of biotech research in developing transgenic rices through incorporating genes of agronomic value may be reviewed in Table 4. Table 5 reports achievements in mapping genes with molecular markers. Progress has been made in herbicide tolerance and insect and

Table 4: Selected studies to illustrate progress in rice transformation

Rice variety	Method used	Gene transferred	Transform. [a]	Trait	Reference
Indica/Japonica	Biolistic	*bar/gus*	H	Herbicide tolerance	Christou et al., 1991
IR 72	Protoplast (PEG)	*bar*	H	Herbicide tolerance	Datta et al., 1992
Japonica	Protoplast	*CP-stripe virus*	M	Stripe virus resistance	Hayakawa et al., 1992
Indica	Protoplast (PEG)	*Chitinase chi11*	H	Sheath blight resistance	Lin et al., 1995; Datta et al., 2000
Japonica	Biolistic/protoplast	*pinII*	M	Insect resistance	Duan et al., 1996
Indica	Biolistic/protoplast	*Bt*	H	Stem borer resistance	Datta et al., 1996; Alam et al., 1998
Japonica	Biolistic	*HVA1*	M	Osmoprotectant	Xu et al., 1996
Indica/Japonica	Biolistic/protoplast	*adh/pdc*	M	Submergence tolerance	Quimio et al., 1999
Indica	Biolistic	*Bt*	M	Stem borer multiple resistance	Tu et al., 1998a
Indica/Japonica	Biolistic/protoplast	*Bt*	H	Stem borer resistance, tissue specific	Datta et al., 1998
Indica	Biolistic	*Xa-21*	M	BLB resistance	Tu et al., 1998b
Japonica	Agrobacterium	Ferritin	M	Iron improvement	Goto et al., 1999
Japonica	Agrobacterium	*psy, crt1, lyC*	M	Beta-carotene	Ye et al., 2000

a. H = more than 100 independent transgenic plants; M = more than 10 independent transgenic plants.

Table 5: Selected studies to illustrate progress in rice gene mapping with molecular markers

Gene	Trait	Chromo-some	Linked Marker	Distance	Reference
Pi-1	Blast resistance	11	Npb181	3.5 cM	Yu et al., 1991
Pi-2(t)	Blast resistance	6	RG64	2.1 cM	Yu et al., 1991; Hittalmani et al., 1995
Pi-ta	Blast resistance	12	RZ397	3.3 cM	Yu et al., 1991
Xa-1	Bacterial blight resistance	4	Npb235	3.3 cM	Yoshimura et al., 1992
Xa-4	Bacterial blight resistance	11	Npb181	1.7 cM	Yoshimura et al., 1992, 1995
xa-5	Bacterial blight resistance	5	RG556	0-1 cM	McCouch et al., 1991
xa-13	Bacterial blight resistance	8	RZ390 RG136	0 cM 3.8 cM	Yoshimura et al., 1995; Zhang et al., 1996
Xa-21	Bacterial blight resistance	11	pTA818 PTA248 RG103	0-1 cM	Ronald et al., 1992
RTSV	Rice tungro spherical virus resistance	4	RZ262	5.5 cM	Sebastian et al., 1996
Bph-1	Brown planthopper res.	12	XNpb 248	—	Hirbayashi and Ogawa, 1995
Bph-10 (t)	Brown planthopper res.	12	RG457	3.68 cM	Ishii et al., 1994
ef	Early flowering	10	CDO98	9.96 cM	Ishii et al., 1994
fgr	Fragrance	8	RG28	4.5 cM	Ahn et al., 1992
Gm-2	Gall midge res.	4	RG329	1.3 cM	Mohan et al., 1994
Rf-3	Fertility restorer	1	RG532	0-2 cM	Zhang et al., 1997
Se-1	Photoperiod sensitivity	6	RG64	0	Mackill et al., 1993
Sub-1 (t)	Submergence tolerance	9	RZ698	—	Nandi et al., 1997

disease resistance, and this will benefit farmers in irrigated ecosystems by stabilizing yields at high levels and increasing profits due to reduced yield losses. Some progress has also been made in developing submergence tolerance and in incorporating iron and vitamin A. These traits have been transformed mostly in Japonica varieties, which are grown in temperate zones in East Asia. These initial successes, moreover, will promote future work to incorporate these traits into Indica varieties that will benefit poor consumers and farmers in unfavorable ecosystems.

6 CONCLUSION

Biotechnology can contribute to future food security if it benefits small and marginal farmers who operate in unfavorable rice-growing environments. Structural and functional genomics will help to identify important genes and their association with agronomic traits. Rice breeders can expedite breeding and improve efficiency with marker-assisted selection techniques. Genetic engineering has already demonstrated the usefulness of introducing valuable traits in rice through transformation, traits that conventional plant breeding approaches have not been able to introduce. But current biotechnology research mostly focuses on traits related to insect and disease resistance. These traits will benefit farmers who operate in irrigated environments with high yields in countries where the demand for rice has been slackening recently. To reach the poor, rice biotechnology research must address the problems of abiotic stresses and human nutrition, problems that are found predominantly in unfavorable rice-growing environments and in regions with marginal lands.

Whether rice biotechnology research will bring benefits to the poor also depends on how we address issues of patenting and intellectual property rights. It is argued that, unless the ownership of intellectual property generated by research is legally recognized and protected, the private sector will not invest in biotechnology research and in the transfer of its products to farmers. But the merger of private sector seed and chemical companies into a few big ones suggests that patenting could lead to knowledge monopolies, restricted access to germplasm, controls over the research process and selectivity in research focus, thus increasing the marginalization of most of the world population (Serageldin, 1999). Furthermore, because of limited effective demand, it is unlikely that the private sector will ever invest in developing products for small and marginal farmers. We have noted substantial investment in research in rice biotechnology from public sector institutions in the developing countries. This needs to be supported, and a mechanism should be developed so that all categories of farmers can access the products of these institutions at affordable prices. However, many of the useful genes are already patented and owned by the big private-sector companies. Accordingly, IRRI and NARSs must also develop new and innovative partnerships with the private sector to bring the fruits of biotechnology research to rice farmers and consumers, particularly those with low incomes. The International Rice Genome Sequencing Project intends to keep its output in the public domain. Public-sector institutes with skills in functional genomics will have an important role to play in gene discovery and in applying these discoveries to molecular breeding. In this way, the fruits of the biotechnology revolution will reach poor rice farmers and consumers.

REFERENCES

Ahn, S., C.N. Bollich, and S.D. Tanksley (1992): RFLP Tagging of a Gene for Aroma in Rice. *Theoretical and Applied Genetics* 84, pp. 825-828.

Alam, M.F., K. Datta, E. Abrigo, E. Vazquez, D. Senadhira, and S.K. Datta (1998): Production of Transgenic Deepwater Indica Rice Plants Expressing a Synthetic *Bacillus thuringiensis crylA (b)* Gene with Enhanced Resistance to Yellow Stem Borer. *Plant Science* 135, pp. 25-30.

Bennett, J. (1995): Biotechnology and the Future of Rice Production. *GeoJournal* 35 (3), pp. 333-335.

Brown, L.R. (1974): *By Bread Alone*. Paeger, New York.

Christou, P., T.L. Ford, and M. Kofron (1991): Production of Transgenic Rice (*Oryza sativa L.*) Plants from Agronomically Important Indica and Japonica Varieties via Electric Discharge Particle Acceleration of Exogenous DNA into Immature Zygotic Embryos. *Bio/Technology* 9, pp. 957-962.

Conway, G. (1998): *The Doubly Green Revolution: Food for All in the 21st Century*. Cornell University Press, Ithaca, NY.

Datta, K., Z. Koukolikova-Nicola, N. Baisakh, N. Oliva, and S.K. Datta (2000): *Agrobacterium*-Mediated Engineering for Sheath Blight Resistance of Indica Rice Cultivars from Different Ecosystems. *Theoretical and Applied Genetics* 100, pp. 832-839.

Datta, K., A. Vasquez, J. Tu, L. Torrizo, M.F. Alam, N. Oliva, E. Abrigo, G.S. Khush, and S.K. Datta (1998): Constitutive and Tissue-Specific Differential Expression of *crylA(b)* Gene in Transgenic Rice Plants Conferring Resistance to Rice Insect Pest. *Theoretical and Applied Genetics* 97, pp. 20-30.

Datta, S.K., K. Datta, L.B Torrizo, M.F. Alam, J. Tu, Y. Fan, K. Altosaar, J. Bentur, and G.S. Khush (1996): Production of Efficient *Bt* Rice and Application. Proceedings of the 2nd Pacific Rim Conference on Biotechnology of *Bacillus thuringiensis* and its Impact to the Environment. Chiang Mai, pp. 401-411.

Datta, S.K., A. Peterhans, K. Datta, and I. Potrykus (1990): Genetically Engineered Fertile Indica-Rice Plants Recovered from Protoplasts. *Bio/Technology* 8, pp.736-740.

Datta, S.K., K. Datta, N. Soltanifar, G. Donn, and I. Potrykus (1992): Herbicide-Resistant Indica Rice Plants from IRRI Breeding Line IR72 after PEG-Mediated Transformation of Protoplasts. *Plant Molecular Biology* 20, pp. 619-629.

David, C.C., and K. Otsuka (1994): *Modern Rice Technology and Income Distribution in Asia*. Lynne Rienner Publishers, Boulder and London.

Dowling, N.G., S. M. Greenfield, and K.S. Fischer (eds.) (1998): *Sustainability of Rice in the Global Food System*. Pacific Basin Study Center, Davis, International Rice Research Institute, Los Baños.

Duan, X., X. Li, Q. Xue, M. Abo-El-Saad, D. Xu, and R. Wu (1996): Transgenic Rice Plants Harboring an Introduced Potato Proteinase Inhibitor II Gene are Insect Resistant. *Nature Biotechnology* 14, pp. 494-498.

Eckholm, E.P. (1976): *Losing Ground*. Norton, New York.

FAO (1999): FAOSTAT Electronic Database. Food and Agriculture Organization of the United Nations, Rome.

Goto, F., T. Yoshihara, N. Shigemoto, S. Toki, and S. Takaiwa (1999): Iron Fortification of Rice Seed by the Soybean Ferritin Gene. *Nature Biotechnology* 17, pp. 282-286.

Hayakawa, T., Y. Zhu, K. Itoh, and Y. Kimura (1992): Genetically Engineered Rice Resistant to Rice Stripe Virus, an Insect-Transmitted Virus. *Proceedings of the National Academy of Sciences USA* 89, pp. 9865-9869.

Hazell, P.B.R., and C. Ramasamy (1991): *The Green Revolution Reconsidered: The Impact of High Yielding Rice Varieties in Sri Lanka*. The Johns Hopkins University Press, Baltimore and London.

Hiei, Y., S. Ohta, T. Tomari, and T. Kumashiro (1994): Efficient Transformation of Rice (*Oryza sativa L.*) Mediated by *Agrobacterium* and Sequence Analysis of the Boundaries of the T-DNA. *Plant Journal* 6, pp.271-282.

Hirabayashi, H., and T. Ogawa (1995): RFLP Mapping of *Bph-1* (Brown Planthopper Resistance Gene) in Rice. *Breeding Science* 45, pp. 369-371.

Hittalmani, S., M.R. Foolad, T.W Mew, R.L. Rodriguez, and N. Huang (1995): Development of PCR-Based Marker to Identify Rice Blast Resistance Gene, *Pi-2(t)* in a Segregating Population. *Theoretical and Applied Genetics* 91, pp. 9-14.

Hossain, M. (1988): Nature and Impact of the Green Revolution in Bangladesh. *IFPRI Research Report* 67, International Food Policy Research Institute, Washington, D.C.

Hossain, M., and P.L. Pingali (1998): Rice Research, Technological Progress, and Impact on Productivity and Poverty: An Overview. In: P.L. Pingali, and M. Hossain (eds.). *Impact of Rice Research*. Thailand Development and Research Institute, Bangkok, and International Rice Research Institute, Los Baños.

Hossain, M., and K.S. Fischer (1995): Rice Research for Food Security and Sustainable Agricultural Development in Asia: Achievements and Future Challenges. *GeoJournal* 35 (3), pp. 286-298.

Huang, N., E.R. Angeles, J. Domingo, G. Magpantay, S. Singh, G. Zhang, N. Kumaravadivel, J. Bennett, and G.S. Khush (1997): Pyramiding of Bacterial Blight Resistance Genes in Rice: Marker Assisted Selection Using RFLP and PCR. *Theoretical and Applied Genetics* 95, pp. 313-320.

Ishii, T., D.S. Brar, D.S. Multani, and G.S. Khush (1994): Molecular Tagging of Genes for Brown Planthopper Resistance and Earliness Introgressed from *Oryza australiensis* Into Cultivated Rice, *O. Sativa*. *Genome* 37, pp.217-221.

Khush, G.S. (1995): Modern Varieties – Their Real Contribution to Food Supplies and Equity. *GeoJournal* 35 (3), pp. 275-284.

Lin, W., C.S. Anuratha, K. Datta, I. Potrykus, S. Muthukrishnan, and S.K. Datta (1995): Genetic Engineering of Rice for Resistance to Sheath Blight. Bio/Technology, Vol. 13, pp. 686-691.

Mackill, D.J., M.A. Salam, Z.Y. Wang, and S.D. Tanksley (1993): A Major Photoperiod Sensitivity Gene Tagged with RFLP and Isozyme Markers in Rice. *Theoretical and Applied Genetics* 85, pp. 536-540.

McCouch, S.R., M.L. Abenes, E.R. Angeles, G.S. Khush, and S.D. Tanksley (1991): Molecular Tagging of a Recessive Gene, *Xa-5*, for Resistance to Bacterial Blight of Rice. *Rice Genetic Newsletter* 8, pp. 143-145.

Mohan, M., S. Nair, J.S. Bentur, U.P. Rao, and J. Bennett (1994): RFLP and RAPD Mapping of the Rice *Gm2* Gene that Confers Resistance to Biotype 1 of Gall Midge (*Orseolia oryzae*). *Theoretical and Applied Genetics* 87, pp. 782-788.

Nandi, S., P.K. Subudhi, D. Senadhira, N.L. Manigbas, S. Sen-Mandi, and N. Huang (1997): Mapping QTLs for Submergence Tolerance in Rice by AFLP Analysis and Selective Genotyping. *Molecular Genetics* 255, pp. 1-8.

Paddock, W., and P. Paddock (1967): *Time of Famines*. Little, Brown and Company, Canada.

Quimio, C., L.B. Torrizo, M. Ellis, E.M. Abrigo, N.P. Oliva, A.R. Vasquez, E.S. Ella, T.L. Setter, A.L. Carpena, O. Ito, W.J. Peacock, L. Dennis, and S.K. Datta (1999): Enhancement of Submergence Tolerance in Transgenic Rice Overproducing Pyruvate Decarboxylase. *Journal of Plant Physiology*, (in press).

Rockefeller Foundation (1994, 1997, 1999): General Meeting of the International Program on Rice Biotechnology: Abstracts. Held in Bali, Indonesia (1944), Malacca, Malaysia (1997), and Phuket, Thailand (1999).

Rola, A.C., and P.L. Pingali (1993): *Pesticides, Rice Productivity and Farmers' Health: An Economic Assessment*. World Resources Institute, Washington D.C.

Ronald, P.C., B. Albano, R. Tabien, L. Abenes, K. Wu, S.R. McCouch, and S.D. Tanksley (1992): Genetic and Physical Analysis of the Rice Bacterial Blight Resistance Locus, *Xa21*. *Molecular Genetics* 236, pp. 113-120.

Sebastian, L.S., R. Ikeda, N. Huang, T. Imbe, W.R. Coffman, and S.R. McCouch (1996): Molecular Mapping of Resistance to Rice Tungro Spherical Virus and Green Leafhopper. *Phytopathology* 86, pp. 25-30.

Serageldin, I. (1999): Biotechnology and Food Security in the 21st Century. *Science* 285, pp. 387-389.

Tu, J., K. Datta, M.F. Alam, G.S. Khush, and S.K. Datta (1998a): Expression and Function of a Hybrid *Bt* Toxin Gene in Transgenic Rice Conferring Resistance to Insect Pests. *Plant Biotechnology* (Japan) 15, pp. 183-191.

Tu, J., I. Ona, Q. Zhang, T.W. Mew, G.S. Khush, and S.K. Datta (1998b): Transgenic Rice Variety IR72 with Xa21 is Resistant to Bacterial Blight. *Theoretical and Applied Genetics* 97, pp. 31-36.

Underwood, B.A. (1999): Micronutrient Deficiencies as a Public Health Problem in Developing Countries and Effectiveness of Supplementation, Fortification and Nutrition Education Programs: Is There a Role for Agriculture? Paper presented in the Workshop on Nutrition and Agriculture, International Rice Research Institute, and International Food Policy Research Institute, Los Baños.

UNDP (1998): *Human Development Report, 1998*. United Nations Development Program, Oxford University Press, New York.

Virmani, S.S. (ed.) (1994): *Hybrid Rice Technology: New Developments and Future Prospects*. Selected papers from the International Rice Research Conference, International Rice Research Institute, Los Baños.

World Bank (various issues): *Quarterly Review of Commodity Markets*. The World Bank, Washington, D.C.

Xu, D., X. Duan, B. Wang, B. Hong, T.H. David, and R. Wu (1996): Expression of a Late Embryogenesis Abundant Protein Gene, *HVA1,* from Barley Confers Tolerance to Water Deficit and Salt Stress in Transgenic Rice. *Plant Physiology* 110, pp. 249-257.

Ye, X., S. Al-Babili, J. Zhang, P. Lucca, P. Beyer, and I. Potrykus (2000): Engineering the Provitamin A (β-Carotene) Biosynthetic Pathway into (Carotenoid-Free) Rice Endosperm. *Science* 287, pp. 303-305.

Yoshimura, S., A. Yoshimura, A. Saito, N. Kishimoto, M. Kawase, M. Yano, M. Nakagahra, T. Ogawa, and N. Iwata (1992): RFLP Analysis of Introgressed Chromosomal Segments in Three Near-Isogenic Lines of Rice Bacterial Blight Resistance Genes, *Xa-1, Xa-3* and *Xa-4*. *Japanese Journal of Genetics* 67, pp. 29-37.

Yoshimura, S., A. Yoshimura, N. Iwata, S.R. McCouch, M.L. Abenes, M.R. Baraoidan, TW. Mew, and R.J. Nelson (1995): Tagging and Combining Bacteria Blight Resistance Genes in Rice Using RAPD and RFLP Markers. *Molecular Breeding* 1, pp. 375-387.

Yu, Z.H., D.J. Mackill, J.M. Bonman, and S.D. Tanksley (1991): Tagging Genes for Blast Resistance in Rice via Linkage to RFLP Markers. *Theoretical and Applied Genetics* 81, pp. 471-476.

Zhang, G., T.S. Bharaj, Y. Lu, S.S. Virmani, and N. Huang (1997): Mapping of the *Rf-3* Nuclear Fertility-Restoring Gene for WA Cytoplasmic Male Sterility in Rice Using RAPD and RFLP Markers. *Theoretical and Applied Genetics* 94, pp. 27-33.

Zhang, G., E.R. Angeles, M.L.P. Abenes, G.S. Khush, and N. Huang (1996): RAPD and RFLP Mapping of the Bacterial Blight Resistance Gene *Xa-13* in Rice. *Theoretical and Applied Genetics* 93, pp. 65-70.

PART III

EXPECTED IMPACTS

OVERVIEW

María Antonia Fernández

Many believe today that biotechnology can dramatically increase agricultural production. But the technology's potential benefits still remain beyond the horizon, particularly for developing countries. The traits and varieties so far developed meet the needs of transnationals (high-input varieties, quality increases, etc.), but it is not yet very clear how smallholder farmers can adopt these technologies and whether they can make a positive impact on the welfare of poor communities.

The debate about biotechnology has focused almost exclusively on genetically modified crops. Yet direct gene transfer is only one tool out of a wide spectrum of biotechnology methods and processes such as microbial fermentation, biological nitrogen fixation, plant tissue culture, embryo transfer in animals, monoclonal antibody production, plant protoplast fusion and recombinant DNA technology for diagnosing plant and animal diseases. Germplasm analysis and improvement are based upon genetic variation, inheritance patterns and the association of desired characteristics with genetic determinants. Two principal sub-fields are discernible: (i) the characterization of genes and the genome structure, and (ii) the characterization of gene functions, gene regulation and the control of complex traits. Translating this genomic knowledge into improved germplasm requires the creation of new gene combinations often achieved through classical plant breeding. Even though there is a wide spectrum of new biotechnologies, the present breeding progress is mainly the result of

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classical breeding, and this will continue. Indeed, a prerequisite for a successful plant-breeding program is the use of both classical techniques and biotechnology. Biotechnology is only an addition to classical techniques, not a replacement for them.

Before beginning any biotechnological breeding activities, we should be careful to ascertain to what degree (if any) they are cheaper, faster, safer, more secure, more durable and more sustainable than classical approaches. Only if biotechnology tools are properly used and efficiently combined with traditional technologies can our economic and ecological goals be achieved. We must also remember that one variety (genetically modified or not) does not fit in every environment. Seeds are planted in different places for different people, and once we obtain a new variety it should be tested and adapted to different farming conditions. These are some of the reasons why an effective and sustainable national agricultural research system is required for the successful deployment of agricultural biotechnology in a developing country. Finally, it needs to be stressed that the outcome of biotechnology is also influenced by social and institutional aspects that are shaped by the relationships between transnational companies, governmental institutions, scientists, public and private research entities and other actors, such as farmers, consumers and environmental organizations. Biotechnology is a prime example of the dual character of cutting-edge technologies, which have both opportunities and risks. It can contribute to scientific and economic development, yet it can also have negative economic, social and ecological effects. In developing countries, it is likely that biotechnology will only contribute to progress and food security when an adequate foundation has been laid in the economic, social and political environments.

This part of the book examines the expected benefits of agricultural biotechnology on developing countries and how these benefits may be enhanced. Any policy aiming to optimize the benefits of biotechnology for the poor should be built on a multidisciplinary approach, one that takes into account the standpoints of all relevant stakeholders. Accordingly, the authors in this part include academic scholars, development practitioners and representatives from private-sector and non-governmental organizations. Little concrete information on biotechnology implications in developing countries is available yet, so any effort to improve our ability to assess and quantify costs and benefits can make a valuable contribution to decision-making processes.

The first chapter by *Gregory Graff et al.* describes the important roles that economic research could and should play in shaping the international biotechnology evolution. The paper argues that economists are in a unique position to provide the knowledge needed to set research priorities, formulate appropriate intellectual property rights (IPRs) and assist institutions in influencing the development and diffusion of new biotechnologies. Furthermore, economists should assess public attitudes towards biotechnology and design policies to address them. To achieve valuable and effective results, however, economic research must be considered in the context of technical, ecological, social, political and cultural factors. This requires much greater and broader analytical work than currently exists. The idea of an IPR regime designed to favor the development of agricultural sciences and biotechnology in developed and developing countries as a first goal seems to be challenging and promising and deserves future special efforts.

The paper by *Matin Qaim* discusses an analytical framework for quantitative impact assessments of biotechnology applications and presents two ex ante case studies related to stress-resistant, transgenic crops in Kenya and Mexico. The examples clearly demonstrate the benefit potentials of biotechnology for poor agricultural producers and consumers. They also show, however, that suitable institutional mechanisms and efficient seed markets must be in place to facilitate safe, widespread use of the new technologies. These case studies are among the first quantitative biotechnology impact assessments carried out in developing countries. In future studies, methodological refinements should be considered to address further relevant questions, such as: how can the sustainable application of transgenic crops with resistances to biotic stress factors be guaranteed in economic and ecological terms? And how can transgenic varieties be a part of integrated pest management programs? Moreover, post-harvest aspects should be considered more explicitly. Is there an adequate infrastructure to efficiently handle and market technology-induced yield gains?

Some institutional issues are broached in the paper by *Margaret Karembu* and *Michael Njuguna*, who present a case study of banana tissue culture technology in Kenya. The achievements in this case-study project appear impressive. The authors state that a participatory approach with good communication systems and multidisciplinary partnerships among all stakeholders is an essential key to success. Still, the analysis of other factors needed to achieve the successful use of biotechnology – such as (i) the assessment of socioeconomic determinants, (ii) the integration of biotechnology with conventional research and (iii) the national policy for agricultural and biotechnological research and new technology adoption – is missing.

Howarth Bouis takes a more technical look at enhancing the micronutrient contents of staple foods for poor food consumers. This analysis of improved product qualities, which has important implications for food security, balances a public discussion that is too focused on biotechnology and food production quantity. More methodological work is needed to quantify the health benefits brought about by micronutrient-dense food commodities. Such studies would make it clear to policy-makers that breeding for micronutrients could provide high social returns on research and development (R&D) investments, whether through biotechnology or conventional approaches.

This part of the book also provides three viewpoints about the potential impact of biotechnology on developing countries. Arguing that biotechnology could help to maintain the balance between supply and demand, *Walter Dannigkeit* gives an overview of the next generation's global food requirements. He argues that the private sector plays a dominant role in biotechnology R&D and will continue to do so in the future. Since seed is the vehicle to deliver biotechnology to farmers, *Suri Sehgal* states in his paper that a vibrant private-sector seed industry is an important precondition for sustainable food production and security. Corporate strategies should be intelligently combined with public-sector efforts. *Christoph Then*, on the other hand, considers the economic interests of the private industry a threat to food security. He claims that genetic engineering would inevitably undermine traditional knowledge systems in developing countries and lead to a monopolization of the entire food production chain. Although Then's notion is surely exaggerated, he is probably right to point out that private-sector efforts need to be channeled by appropriate institutional mechanisms to ensure that biotechnology does not cause undesired social problems for the poor.

Analyzing the potential impacts of "Terminator" technologies designed by private companies to restrict the use of purchased seeds only to the first generation *Timo Goeschl* and *Timothy Swanson* also stress this. Such genetic use restrictions are expected to hamper the international diffusion of biotechnology innovations. This would also obstruct an equitable sharing of benefits arising from the exploitation made by the new biotechnological methods applied to the existing varieties, carrying centuries of traditional knowledge and conventional breeding work performed by poor communities and public-sector research institutions. Indeed, without appropriate public policies, these efforts to protect intellectual property will negatively affect many developing countries.

When coupled with other technologies, biotechnology is a powerful agricultural development tool with great potential – both positive and negative. It offers possible solutions for many problems in developing countries, and national programs should mobilize research and establish innovation policies to tap its potential. They should also seek to ensure that the benefits of the new technology will enrich everyone, especially poor rural populations in marginal areas where productivity increases are difficult to achieve.

Chapter 8

THE ROLES OF ECONOMIC RESEARCH IN THE EVOLUTION OF INTERNATIONAL AGRICULTURAL BIOTECHNOLOGY

Gregory Graff, David Zilberman[#], and Cherisa Yarkin

Abstract: This paper identifies several areas where economic research can make a difference in agricultural biotechnology's evolution and suggests fields of related research emphasis. Also, methodologies are identified that need improvement to provide guidance for managing biotechnology policies. First of all, recent trends in biotechnology research that may affect agriculture in developing countries are discussed. The paper then outlines several types of economic research on biotechnology, including technology adoption, ex ante analysis of biotechnology's economic impacts and institutional and policy designs. It is argued and shown that economic analysis can help to improve (i) the allocation of research resources, (ii) intellectual property rights arrangements, (iii) technology transfer, (iv) the structure of private and public research, (v) the conservation of genetic materials, (vi) the farm-level adoption of biotechnology innovations and (vii) the direct and indirect impact of biotechnologies on farmers and consumers.

1 INTRODUCTION

Global population has increased six-fold during the twentieth century, and, despite this enormous growth, actual food production per capita has increased. Between 1950 and 2000, grain production per person increased by 15 percent while acres harvested per person declined by 50 percent. To a large extent, these achievements are the result of the introduction of improved varieties. In the early twentieth century, improvements in yield were enabled by basic Mendelian principles of genetic inheritance, and

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improved breeding techniques were elaborated from these discoveries. The revolution in information technologies and in molecular and cell biology during the 1960s, 70s and 80s provided the foundation for a new approach to yield improvements through the use of biotechnology. However, regardless of technological feasibility, the acceptance, use and impact of biotechnology in agriculture in general and in developing countries in particular depend upon the design of institutional policies. Economic research provides the crucial knowledge base needed to formulate policies that will shape the future and impact of biotechnology in agriculture.

2 STYLIZED FACTS ABOUT THE ECONOMICS OF INNOVATION IN BIOTECHNOLOGY

The evolution of biotechnology, first in medicine and more recently in agriculture, has provided us with enough experience and economic and institutional knowledge to make several important generalizations.

2.1 Importance of University Research and the Process of Technology Transfer

Practitioners have played an important role in generating many crucial technologies in the past, including electronics and aviation (for a review see Mowery and Rosenberg, 1979). However, basic research conducted in universities (for example, the work of Cohen and Boyer at the University of California at San Francisco and Stanford University) was crucial in establishing the fundamental techniques and processes that led to the commercial use of biotechnology. With changes in technology transfer policy at the federal level beginning in 1980, it has become possible for commercial enterprises to selectively license the rights to utilize knowledge from public institutions.

2.2 Intellectual Property Rights and Offices of Technology Transfer

The US government grants patents and similar intellectual property rights (IPRs) to discoveries that enable modification of living organisms (Rausser and Small, 1996). The Bayh-Dole Act from 1980 allows public research institutions to patent discoveries made with public monies. Together these policies have led to the establishment of Offices of Technology Transfer (OTTs) in US universities and research institutes, to take patentable ideas from public researchers and sell or license their rights to entities in the private sector. Currently, there are close to 200 OTTs in research institutions in the US, and more than 80 percent of these were established in the last 20 years.

Several surveys (Postlewait, 1993; Parker and Zilberman, 1993; Castillo et al., 1999) find that the major objectives of OTTs have been to increase the utilization of university knowledge and to generate university income. In recent years (1996 and 1997) collective annual revenues of the OTTs exceeded US $500 million. Altogether they provided about 10 percent of the official research budget of universities in the US, and less than 1 percent of the total budget of higher education institutes. More than 40 percent of the revenues come from medical biotechnology patents. Revenues are typically shared among the university, researcher and department. Most often, the sharing rule is one-third for each. In other cases it is two-fifths for the university, two-fifths for the researcher, and one-fifth for the department or simply a 50-50 split between the university and the researcher.

A small number of innovations generate most of the OTT revenues. The top 10 percent of patents exceed 50 percent of total revenues; the Cohen-Boyer patent earned more than US $100 million, which is consistent with other evidence that patent values are highly skewed (Scherer, 1965; Griliches, 1987). Leading research universities accumulate the lion's share of biotechnology patent licensing revenues. The University of California and Stanford University, the two leading earners in the mid-1990s, grossed more than 20 percent of total national OTT revenues. In most cases compensation for the right to use university innovations is paid in cash, but payment with equity has also grown in importance, particularly in the case of the Massachusetts Institute of Technology (MIT).

2.3 Importance of Startup Companies and Venture Capital

Interviews with directors of OTTs suggest that they expect the main buyers of rights to be established companies. However, many of the crucial biotechnology patents cover technologies in their early stage, which do not attract established companies. In many cases, OTT officers mediate between the university researchers and venture capitalists to establish small startup companies devoted to commercially establishing and developing the technology represented in the new patents.

The involvement of university researchers with these small startup companies seems to be crucial, and a primary reason that university researchers become shareholders and officers in these firms is because they hold the tacit knowledge essential for development of the new technologies.

Some of the most substantial innovations in biotechnology evolved in this way.

Companies founded by university faculty, such as Genentech and Chiron, were integral in establishing the commercial medical biotechnology sector. Companies built on technologies licensed from universities, such as Calgene, DNA Plant Technologies, and Mycogen, were crucial in establishing the commercial agricultural biotechnology sector. De Janvry et al. (1999) traced the ownership of patents essential to developing pest-resistant plants in agriculture and found that at first the majority of patents (including the crucial breakthroughs) were held by research institutions. Later the majority were held by small companies; and finally, by major multinational corporations. That study corroborated an observed trend in agriculture of multinationals taking over small startup companies that own new technologies in order to incorporate them within their corporate research program. This explains in part, for example, how Monsanto has developed a number of its traits for genetically modified (GM) crop varieties.

More generally, while major corporations have invested heavily in research and development (R&D), they have seemed content to let startup companies experiment with the more uncertain cutting-edge innovations – allowing them to take risks that the established companies seem unwilling to bear – and then to acquire the successful ones (Pisano, 1988). Through this process, some corporations have established or amassed an in-house upstream research capacity in biotechnology and thereby have themselves become major sources of innovation. At the same time, major corporations have become more willing to bypass startup companies and to link directly with university researchers. One example of such a contractual relationship in agricultural biotechnology is the Novartis-UC Berkeley contract (see Rausser, 1999). Other recent arrangements have involved DuPont with MIT and the University of Delaware.

2.4 Biotechnology Innovations Enable Targeted Genetic Improvement

Traditional plant breeding involves crossing a large number of individual varieties and finding a rare progeny with desirable properties among hundreds or thousands of offspring. Biotechnology generates new varieties by modifying or inserting a single gene or a small set of genes to an existing variety. The change in the particular trait of interest may be substantial, since the genetic materials may be obtained from an organism that is taxonomically quite distant from the variety to be modified (a feature which, indeed, is a source of environmental and health concerns). Yet, with biotechnology, the modification is done systematically and the improvement of genetic materials may be done in a targeted, controlled way. Thus, in most cases a genetically engineered modification can be thought of as a shift in one dimension of a variety's collection of traits, as opposed to a gross leap from one bundle of traits to an altogether different bundle of traits. Because of the highly complex mapping from genotype (DNA sequence) to phenotype (organism), the change in a single gene may or may not produce a marginal change in the organism. Some genetic modifications cause incremental changes along a particular phenotypic dimension – like enhanced solids or modified fat profiles – while others cause major discrete shifts – such as the expression of novel proteins in a plant's tissues.

2.5 Biotechnology is Leading to a Wide Array of New Innovations in Agriculture

Biotechnology provides many new ways to fundamentally improve plant growth and outputs. By working with the mechanisms of nitrogen fixation, photosynthesis, nutrient availability and resource apportionment, basic improvements can be made in plant metabolism and production efficiency to increase yields. Adjustments can be made in plant morphology such as grains with shorter stalks or seedless fruits. Production can be enhanced by changes in developmental pathways or life cycle timing to allow crops to grow at more or different times of the year, or in different climates. We are able to increase yields by inserting resistance traits or by enhancing natural plant defenses against viruses, microbes, nematodes, fungi, molds and mildews. Biotechnology provides opportunities for alternative means to control insect and weed pests through insect-resistant and herbicide-resistant varieties. We can also improve plants' stress tolerance, including their ability to withstand drought, salinity, acidity, toxic metals and excessive heat and cold. In addition, biotechnology allows much greater control of plant reproduction, making hybrid production much quicker and easier with male-sterile and self-incompatible varieties. It also promises to turn the asexual reproduction of desired varieties into a simple one-step process called apomixis, which coaxes a plant to generate clones of itself in its own seeds.

Another line of biotechnological advancements, outside of direct manipulation of the plant genome, includes bio-based anti-pathogenic and disease treatment cultures and compounds – including bio-based anti-viral, antibiotic, nematocidal, funcigidal and insecticidal treatments – as well as plant growth regulating compounds.

Biotechnology is leading to improved food and animal feed quality by optimizing protein, oil, sugar, vitamin and mineral contents of crops, not to mention modifications such as the levels of caffeine in coffee or the nicotine content of tobacco. Fruits and vegetables are being designed that have improved shelf life with delayed ripening and better flavor. The fiber structure of cotton or flax can be modified for better textiles. Changes in the structural chemistry of wood make paper production easier, and genetic alteration of wood pigmentation allows for color choice in timber products. Optimized acidity or solids content in tomatoes make them more suitable for processing and canning. It is possible to modify plants and livestock to produce valuable materials – be it oils, fine chemicals, nutrients, pharmaceuticals, vaccines, human enzymes (like insulin) and, with livestock, transplant organs for humans.

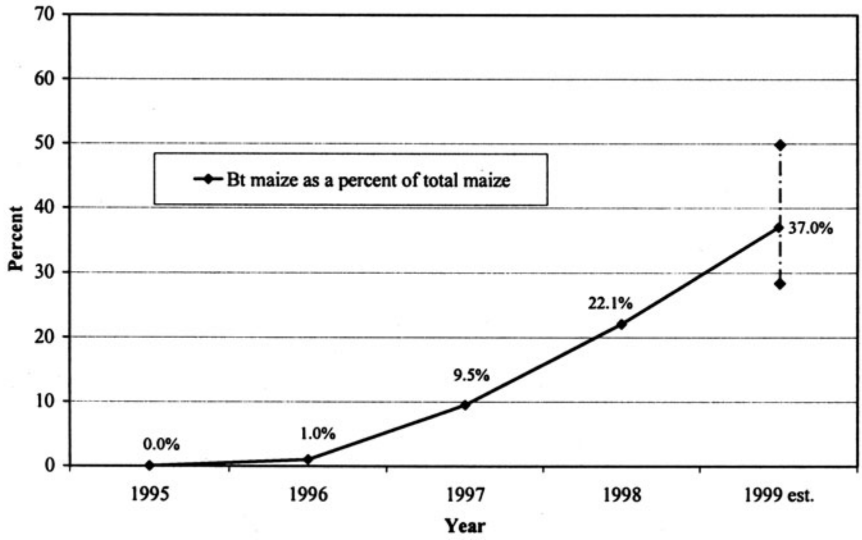
Biotechnology is providing new plant diagnostics, for fast and inexpensive detection and analysis of infestations. Genetic improvements are being made in microorganisms linked to the metabolism or performance of plants such as nitrogen fixing bacteria. Molecular and genetic analysis of plant insect pests and disease pathogens could enable novel control strategies, including the genetic modification of the pests themselves. Molecular markers can be used to track pest reproduction and spread, and the resulting knowledge can be used to develop molecular bio-based components for behavioral or environmental pest control in integrated pest management (IPM) techniques. Biotechnology provides new tools for the assessment and control of insect resistance to insecticidal compounds. Plants can be modified for special roles in the environment, including bioremediation (the absorption or processing of salts, toxins or other pollutants for environmental cleanup, biodegradation and composting).

2.6 Adoption of GM Varieties Has Been Fast but Has Encountered Consumer Resistance

The adoption of GM plant varieties in the last three years has been fast. Crops like *Bacillus thuringiensis* (*Bt*) maize (see Figure 1) and herbicide-resistant soybeans have been planted in an estimated 50 percent of the crop's acreage in developed countries (see de Janvry (1999) for more details). According to the United States Department of Agriculture (USDA), recombinant bovine somatotropin (rBST), also called bovine growth hormone (BGH), has reached a penetration level in the US that exceeds 30 percent. However, this rapid diffusion has seen a concomitant growth in consumer concern over using GM products and even active resistance and pressure for legislation to label these materials or to increase the stringency of requirements for their approval and release.

These important generalizations constitute stylized facts of the technology change process that the biological and agricultural industries are undergoing. They represent key new research topics that economists can and

Figure 1: Bt maize coverage in the US



Sources: Data for years through 1998: James (1998). The range of 1999 estimates is combined from various sources.

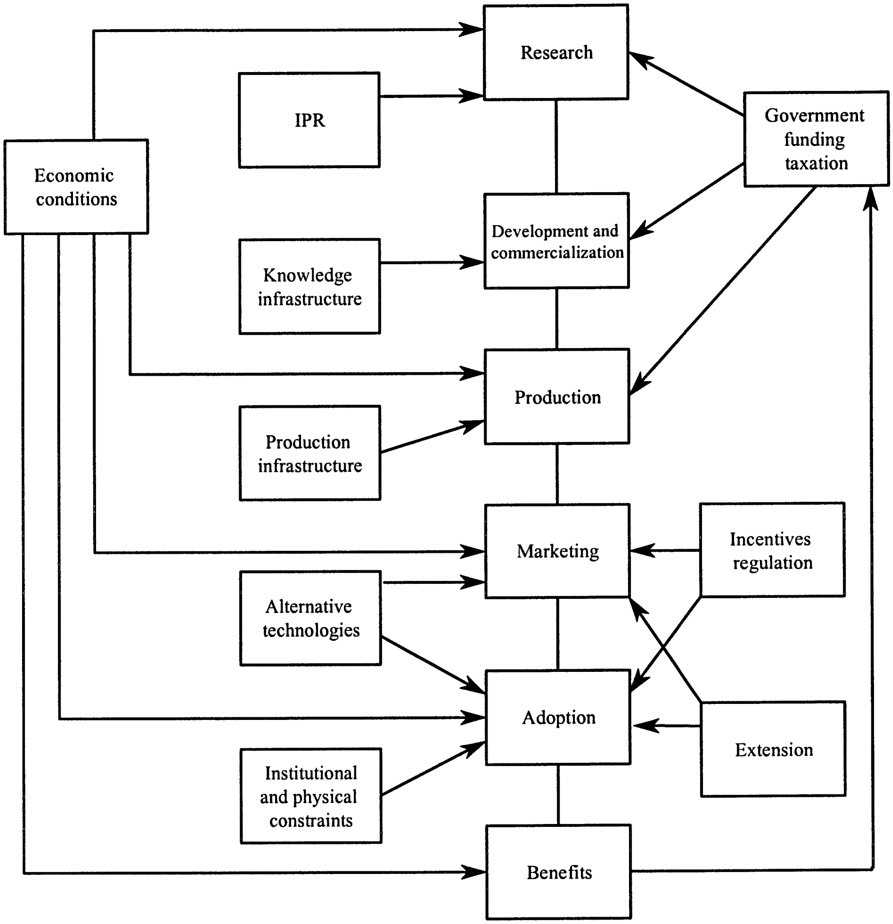
should be pursuing in order to inform institutional and policy formulations that will shape the future of agricultural biotechnology and its economic and social impacts in both the developed and the developing world.

3 STAGES IN THE EVOLUTION OF INNOVATIONS: A FRAMEWORK FOR ECONOMIC ANALYSES

Regardless of whether new innovations are "technology-pushed" or "demand-pulled", as has been distinguished since Schmookler (1962) (see Mowery and Rosenberg, 1979), all successful new technologies go through an evolutionary process that affects both their technological development and their introduction to the market. Figure 2 depicts the stages of evolution for a new agricultural innovation. As an example we consider an embodied biotechnology innovation that results in a marketable product: a new seed variety.

At the first stage in Figure 2, the new agricultural biotechnology begins its life in a research project that is triggered by economic conditions. It is affected in particular by government funding allocations or tax regulations that have made it profitable for companies to invest in R&D (David, 1999).

Figure 2: The stages of evolution of a new agricultural innovation



For example, a genetic manipulation of plants that has a beneficial effect (e.g., reduces pest damage) is identified. The development and adaptation of the innovation toward a specific application in a specific market together constitute the second stage of the new innovation's evolution. In our example, efforts are required to identify existing seed varieties that can benefit from genetic transformation with this new trait. They must be successfully transformed. Test plots are grown and analyzed to ensure that expected outcomes occur predictably and that there are no undesirable side effects. Regulatory clearances are obtained. Then efficient procedures of production are designed.

The third and fourth stages in the new variety's evolution include the actual large-scale production of seeds for sale to final users and marketing endeavors that include identifying potential markets, developing appropriate marketing channels and establishing pricing and sales policies (for example, warranty, product stewardship, etc.). The fifth stage is adoption of the new biotech seed variety by growers, resulting in commercial use and integration of the new variety into the food supply. In the sixth and final stage, overall economic benefits and other impacts can be assessed. In particular, the shape of consumer demand for products made from the new variety (directly or as a constituent of other products, such as corn syrup in sodas and candies) determines the ultimate value of the new variety to growers, and therefore to the initial technology providers. Consumer demands may also result in imposition of regulations that increase the cost of bringing agricultural biotechnology products to market, as we have seen in Europe.

As Figure 2 suggests, each stage is affected both by government policies and the actions of individual economic agents – be they R&D managers, production managers, marketing directors, extension specialists, farmers who adopt the technology or consumers who purchase their products. Economic analysis can play a role in each stage of an innovation's evolution, and the results of economic analysis are useful for decision-makers at each stage. Decision-makers at each stage generally require some knowledge of (at least potential) outcomes at other stages throughout the entire technology evolution process. For example, a marketing director needs a good assessment of adoption patterns under varying strategies to determine an optimal marketing policy. Decisions regarding investment in alternative lines of research require knowledge of adoption potential, regulatory requirements, profitability of each product and other elements such as the costs involved in different lines of research or potential spillovers between different lines of research. Realistically, however, few of these factors can be known ahead of time with certainty.

Agents involved in the innovation evolution process face three types of uncertainty: technological uncertainty, strategic uncertainty and market uncertainty (Encaoua, 1998).

1. *Technological uncertainty.* Since an actual innovation usually cannot be completely anticipated at the research stage – even when there is an explicitly defined need to develop a specific kind of improved technology – the search and discovery process for knowledge that enables an improvement may be quite uncertain. As a result, in a dedicated R&D effort, both timing and cost of the resulting technology are uncertain. Unforeseen technical hindrances to the transfer and commercialization of a technology add to this uncertainty, as do unforeseen technical problems in its adoption and application. However,

there is also an upside to technological uncertainty. It is not unusual for research efforts to discover or create inadvertently a technology that was unplanned and yet is nonetheless quite valuable – at least to someone.

2. *Strategic uncertainty.* When resources are devoted to develop a new technology, the originator cannot be certain of appropriate sufficient returns on the investment because of strategic challenges (Teece, 1986). Competitors may control key complementary assets, without which the value of the innovation cannot be captured. Partial disclosure of a technology or release of an imperfect technology may give enough information to a competitor to allow them to be able to develop the technology earlier or further and to capture the value of the innovation.
3. *Market uncertainty.* Even when the innovator can be certain of the technical feasibility of an innovation and is confident in his strategic position to appropriate returns from the technology, uncertainty remains as to whether there will be a destination for the technology. Potential adopters face uncertainty over how much or even whether different types of consumers will demand the products that result from the application of the technology. Encaoua (1998) emphasizes that this type of uncertainty is both the most difficult to form expectations about and potentially the most influential on the value of the technology.

Furthermore, it should be noted that asymmetric information in the face of these uncertainties complicates bargaining between agents at any point of transfer in an innovation's evolution process. The inventor and the adopter as well as the public regulator (Wright, 1983) typically have different information about the different parts of the innovation evolution process, and thus make different valuations of the technology at crucial bargaining points in the evolution process.

In the remainder of this paper we take a recursive approach in presenting the contributions that economic research can make to agricultural biotechnology. Ex ante study of the economic factors that arise relatively late in the evolution of new biotechnologies – such as adoption by growers, consumer demand for GM foods and direct or indirect environmental and welfare effects – is essential to inform decisions that arise earlier in the product's evolution, such as biotechnology research policies, public funding of new lines of research or the design of new biotechnology products and production systems. In effect, we are arguing that agricultural biotechnology needs to be examined more from a "demand-pull" perspective than from the predominant "technology-push" perspective taken by many analysts and industry pundits to date.

4 ECONOMIC RESEARCH ON THE ADOPTION OF BIOTECHNOLOGIES IN AGRICULTURE

Arguably the key step by which consumer demand "pulls" new biotechnological developments in agriculture lies in the economic decision by farmers to adopt new biotechnologies in their production. We will therefore first discuss the contributions of economic research on technology adoption and diffusion in order to explore the related implications for land use, agricultural supply, price and production levels and ultimately for the well-being of consumers, producers and the environment.

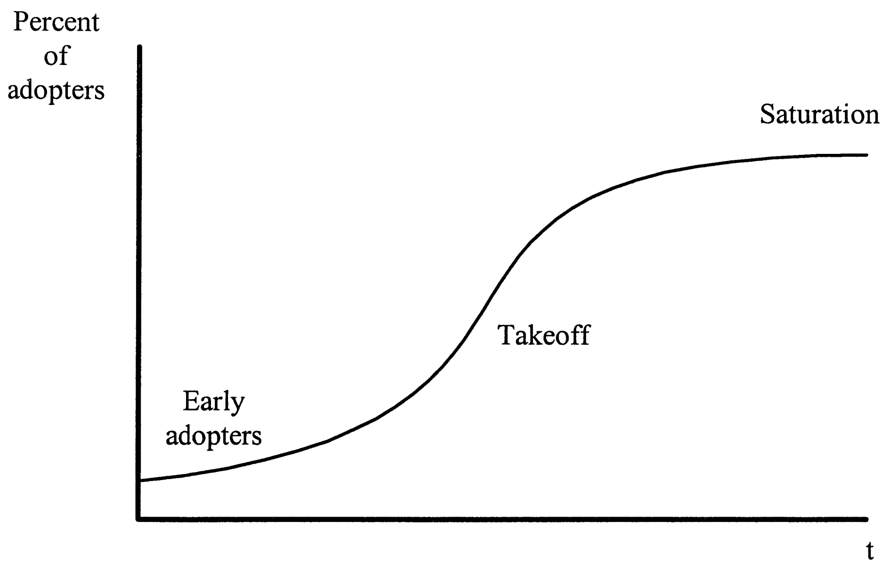
4.1 Technology Diffusion and Adoption

Diffusion of a new technology within regions does not occur instantaneously, but rather gradually. Evidence shows that diffusion, measured by the acreage of the new variety and the percentage of farmers who use the new technology, tends to be an *S*-shaped function of time (see Figure 3). One explanation of this shape was presented by Mansfield (1961), who viewed diffusion as a process of imitation that spreads like a disease or infection. In the beginning, there are a few individuals who adopt a technology, and the number of imitators increases only gradually during the early stages. Once a critical mass of users is established, the technology goes through a takeoff stage. As this stage ends, adoption slows; the technology reaches a saturation point and sometimes declines thereafter. Mansfield argued that the speed of the diffusion process depends on economic profitability – the more profitable the technology, the faster it will diffuse.

More recent studies have introduced alternative theories, which argue that, while information and imitation lead people to consider new technologies, the choices regarding adoption are explicit economic choices, and the *S*-shape of the diffusion curve reflects heterogeneity among farmers and dynamic processes of learning-by-doing and learning-by-using. *Learning-by-doing* occurs at the level of the technology provider; it is a process of increasing efficiency in the production of a new technology over time, which increases efficiency and reduces the cost of the new technology to adopters. *Learning-by-using* occurs at the level of the technology adopter, and represents an increase in efficiency-of-use of the technology over time as the user accumulates more experience with the new technology. Thus, if the population of potential adopters varies with respect to human capital, size or agroclimatic conditions, the early adopters will be individuals who have the most to gain from the technology because of their specific skills or farming situation. They may constitute a small minority in the tail of the population distribution. But after the price of the technology declines, after the risk associated with it diminishes, and after experience with its use accumulates, a larger mass of the population will adopt it, until the saturation point of the diffusion process is reached. Recent econometric studies have verified the importance of heterogeneity in explaining adoption and diffusion patterns and have also attempted to identify the key factors that explain when and where new technologies are introduced (Green and Sunding, 1997).

In the case of biotechnology, it will be very important to develop an econometric assessment to analyze actual data or factors that explain observed adoption patterns. However, this type of study requires waiting until more information is accumulated and is thus of limited value in the initial design of marketing strategies or policies that affect adoption of biotechnology innovations. Therefore, economists should rely on existing empirical studies (i) to obtain estimations of parameters such as adopters' attitudes toward risk, (ii) to identify the importance of constraints such as credit availability in different regions, and (iii) to develop measures of heterogeneity. One important emphasis of research will be profitability analysis of new versus prior technologies under alternative assumptions to assess the riskiness and likelihood of adoption under various conditions. There is a growing literature on technology adoption in developing countries (Feder et al., 1985; Sunding and Zilberman, 2000). When considering the

Figure 3: The technology adoption curve



option of an existing variety versus a new biotechnology variety, users are likely to select the technology with the higher expected profit, adjusted by risk, if their credit constraints are met.

What follows is a simple analysis of the adoption of a new GM variety adapted from Just and Zilberman (1983). We will assume that individuals select technologies that maximize expected returns adjusted for the cost of risk.[1] Suppose a farmer compares the present variety, denoted by $i = 0$, to a genetically modified variety, denoted $i = 1$. Each variety has a mean and a variance of profit denoted by U_i and V_i, respectively. Assuming first that there is no constraint, the optimal technology choice is

$$(1) \qquad \max_{i=0,1} \{U_i - \gamma V_i\}.$$

The expected profit of technology i can be decomposed to

$$(2) \qquad U_i = PY_{i,\exp} - C_i - W_i,$$

where P is the output price, $Y_{i,\exp}$ is the expected yield, C_i is the production cost, and W_i are seed costs. We will assume for now that seed costs for both technologies are the same, W_0 and $W_1 = W$. With this notation, it is clear that the GM variety is selected if

$$(3) \qquad P\Delta Y_{\exp} + \Delta C - W_1 - \gamma \Delta V \geq 0,$$

where $\Delta Y_{\exp} = Y_1 - Y_0 =$ expected yield effect

$\Delta C = C_0 - C_1 =$ production cost effect

$\Delta V = V_0 - V_1 =$ risk effect.

When a new technology is first introduced, there may be a significant amount of technology risk that is based on uncertainty about its genetically modified properties.[2] Even though the technology in the GM variety may eventually reduce a farmer's routine production risk, the initial effect on adoption is negative because of the new GM variety's technology risk. Over time, ΔV grows closer to an objective difference in risk between the old and the new varieties; it comes to reflect differences only in production risk as

[1] This is equivalent to maximization of a linear function of mean and variance of profits which, in turn, is equivalent to expected utility maximization with exponential utility and normal distribution of profits (Collender and Zilberman, 1985).

[2] This "technology risk" for the farmer includes aspects of the three components of uncertainly discussed in section 3 above: technological uncertainty (Will the GM technology work in my case?), strategic uncertainty (If I use this technology will I be locked into or out of certain supplier relationships?), and market uncertainty (Will I be able to sell the harvest at a price that covers cost?).

the technology risk approaches zero. Consider, as an example, a new variety that provides resistance to a pest that was not controlled well before. This new variety has a positive yield effect, reduces the pest treatment cost and has a positive cost saving effect, thus reducing the grower's overall risk. However, it will be adopted only if the extra cost of the seed is smaller than the sum of the benefits. Given heterogeneity between regions and W is uniform, adoption will occur only where pest damage and prices are sufficiently large to overcome the new variety price. Heterogeneity between regions therefore suggests that price discrimination will enhance adoption as well as revenues to the provider of the new technology.

When it comes to poor farmers in developing countries, adoption may be affected by credit constraints. So, when a farmer obtains only M dollars, if $C_0 < M < W + C_1$, adoption is not feasible, even if the new technology is more desirable. In many situations adoption may be facilitated by the provision of credit to constrained farmers. This suggests that economic research can identify adoption patterns under alternative policies, including pricing regimes and credit provision. Capacity to assess adoption under various conditions may enable assessment of an outcome where seeds are produced and marketed by a monopolistic seed company and distributed or subsidized by government.

4.2 Adoption of GM Varieties and Changes in Land Use

As the literature on adoption indicates, farmers generally diversify their lands because of risks and resource availability (usually labor constraints). Thus, the study on adoption of new GM varieties should not only address its performance relative to the existing variety, but should examine the possibility of its adoption on lands used by other crops or lands left idle. If farmers, for example, grow wheat and sorghum and the genetically modified version of sorghum has a higher yield and lower risks and prices do not change, the adoption model of Just and Zilberman (1983) suggests that the acreage of sorghum will increase relative to the acreage of wheat. Furthermore, in many situations, one disease may prohibit adoption of a certain crop at various locations. For example, it has been suggested that adoption of grapes in Florida was prevented by the inability to overcome Pierce's disease. Development of GM varieties that overcome this disease could lead to adoption of grapes in Florida. Thus, economic analysis should identify opportunities to adopt new GM varieties and overcome obstacles that prevent the adoption of crops in certain locations where it otherwise might have been profitable.

One of the major benefits of developing GM varieties is overcoming obstacles in agricultural production resulting from environmental conditions.

Agricultural biotechnology advocates hope that, with genetic engineering, farmers in developing countries will be able to overcome diseases, problems with water quality and salinity and land-quality constraints where no other systemic agronomic or environmental remedy has been effective. Adoption studies should be used to identify actual and potential changes in land-use patterns. These changes often have strong implications for the demand of other inputs – machinery, fertilizers, etc. For example, when a new pest-resistant GM variety is introduced, its adoption may lead to a reduction in the use of a chemical that currently combats the pest. If the adoption studies are accompanied by policy experimentation and if policy-makers are concerned with the negative side effects of the chemical, the adoption of the new GM variety may be encouraged by introducing negative incentives for chemical use, e.g., taxes, banning subsidies for pesticide use or stricter pesticide-use regulations.

Antle and Just (1991) use Hochman and Zilberman's (1978) microparameter distributions model to lay a general framework for combining "bio-physical" and economic models at a disaggregate level, estimating agricultural production processes, and then aggregating the results for the purpose of regional and national policy analysis. Vectors of environmental attributes and agricultural inputs are incorporated into an economic production model along with a vector of policy parameters to generate a vector of agricultural and environmental outputs. A description of the particular interrelationship between any two variables of interest is then obtained by integrating out their joint marginal distribution from the aggregate multivariate joint distribution. The marginal distribution of a single variable can be integrated to obtain values of interest.

This type of microparameter distributions approach can be modified for the analysis of agricultural biotechnologies (see Shah (1995) for an adaptation of the methodology to analyze irrigation technology adoption). The farmer's choice vector, with agricultural input characteristics x and land use δ, simply needs additional breadth and flexibility of choices to reflect the alternative technologies. If we include new genetic inputs x_g, as well as choices of other biological parameters of the model that can be adjusted by biotechnology, call them γ, the farmer now faces a larger menu of choices, $[x, x_g, \gamma, \delta]$. After aggregation, relationships among traditional technology inputs, newly adopted biotechnologies, land use, and output as well as environmental attribute and policy variables could be analyzed at regional and national levels to study aggregate effects of biotechnology adoption.

4.3 Effects of Adopting GM Varieties on Output Supplies and Input Demand

Varying economic and policy conditions, including input and output prices, credit regulations and such, are key elements in deriving supply of agricultural outputs as well as demand for inputs (see Just and Zilberman, 1983). This is especially important in developing countries, where markets for agricultural commodities are local and growers face negatively sloped input demand.

While the introduction of, for example, an improved sorghum variety increases sorghum acreage, it greatly increases supply when output prices are fixed. The derivation of the supply curve and the general equilibrium analysis where supply and demand curves intersect may actually suggest that the supply-increasing effect of the GM variety reduces output prices and thus the actual acreage of sorghum, which provides more acreage for an alternative crop, such as wheat. In this case, the adoption of a GM variety may reduce the acreage of sorghum and at the same time lead to an increase in output of both sorghum and wheat.

4.4 Interdisciplinary Cooperation in Adoption Research

A comprehensive study on the potential adoption and land-use impact of new GM varieties requires interdisciplinary cooperation between economists and members of other disciplines, such as agronomists, crop breeders, entomologists, etc. Economists need to utilize such approaches to make good assessments of the potential impacts of new technologies on yield, cost of production, alternative input use, and such.

Computer geographic information system (GIS) technologies may make this line of cooperation easier. Existing GIS data on land use and parameters regarding land quality, climatic variation and disease problems can provide key components for comprehensive adoption and land-use studies. For a suggestive example of GIS analysis of determinants of land use and adoption of irrigation technologies, see Osgood (1999).

In a similar vein, increasingly complex agricultural ecosystem computer models calibrated to agronomic data can simulate the impacts of new and hypothetical genetic varieties over heterogeneous land qualities, climactic conditions and agronomic practices. In a complex biophysical model like EPIC (Williams et al., 1983), which calculates the biological processes that make for plant growth and yield, a genetic modification of a crop simply involves adjustment of crop-specific biological parameters input to the program to reflect resulting differences in its biological processes. The genetics of the plant determine the parameters of its processes within an ecosystem, which in turn determine its yield function of harvest output. For example, a plant genetically modified for drought tolerance would be assigned a lower parameter for water stress susceptibility than a genetically unmodified variety. In the event that the climate is unexpectedly dry during the simulated growing season, the lower water-stress parameter would lead to a higher predicted harvest yield for the variety with the gene. A valuable aspect of such simulation studies would be that they can be conducted without actually creating or planting the GM crops of interest. For an example of a computer agroecosystems model used in a simulation analysis of economic impacts of alternative cropping systems, see Foltz (1995).

5 EX ANTE ANALYSIS OF THE IMPACT OF GM ADOPTION ON PRICES, OUTPUT AND RESOURCE ALLOCATION

Our analysis has suggested that investigating the adoption of new GM varieties is a starting point for determining land-use patterns and supply responses. These can then be used to establish prices, output levels and the impacts of new technologies on farmers' and consumers' welfare. In many situations in developing countries, the main purpose of a GM variety may be to improve the quality of life and the nutritional well being of the poor, an outcome that can be identified only by general equilibrium analysis.

5.1 General Equilibrium Analysis of Biotechnology Adoption Impacts

De Janvry and Sadoulet (1992) as well as Taylor and Howitt (1993) overview alternative approaches to general equilibrium analysis within the development context. Some of the more disaggregate, data-intensive, detailed programming models that rely on interdisciplinary cooperation and detailed specification of heterogeneity (see Taylor and Howitt, 1993) are particularly useful in assessing the special adoption patterns of GM varieties under various conditions. In spite of significant progress (Howitt 1995), these models must be further perfected to incorporate behavioral parameters econometrically estimated from observed data on actual adoption patterns. Some of the more aggregate computable general equilibrium (CGE) models reported in de Janvry and Sadoulet (1992) may take the results from a programming model and then use them to assess the distributional effect of GM varieties within the economy (see, for example, de Janvry et al., 1999).

The general equilibrium models are essential to assess the general overall impact of new GM technologies in agriculture and the economy as a whole. Furthermore, as we will argue below, they provide crucial information about the design of research programs and pricing strategies. Because of their size, however, these models abstract from many important details in individual locations. In the early stages of developing a general equilibrium analysis of the more aggregate relationships, economists should put significant effort into micro-level farm or regional analyses – both conceptual and empirical (including simulations) – to study applications of new varieties by individual growers or small groups of growers. The various impacts of a new technology on production practices (such as inputs, time management, etc.) should be embodied in these micro-level economic decision-making models. These may then provide new and sometimes unexpected insights that will indicate which aspects to emphasize in general equilibrium analysis. Such insights will also help to determine which elements of policy design have the most impact on the adoption and use of new GM varieties.

5.2 Design of Biotechnology Products and Production Systems

As biological knowledge evolves, we will learn about a variety of gene sequences that give desirable properties for crop and animal production. One of the challenges will be to determine which biotechnology products will be suitable in which of various locations. GM varieties are likely to be stacked with several traits, but it is likely that the marginal cost of inserting additional stacked traits will be increasing in the number of stacked traits because of the complexities that it appears to entail. Furthermore, the insertion of traits may require payment of royalties to trait providers.

For suppliers and generators of biotechnology products, economic research can help to determine exactly what to offer. The design of products has to take into account the objective of the supplier (for a seed company, it will likely be profit maximization; for a government agency, social welfare maximization), the cost of producing different GM varieties and farmers' willingness to pay for the alternative, stacked varieties (which eventually determines adoption). This type of micro-level economic analysis may be quite challenging.

The derivation of demand for each possible product design has to consider complementary and substitutionary choices of other inputs including chemicals, water and machinery, as well as tillage, pest and land management practices. Thus, at the same time that the design of GM varieties depends on the market structure for seeds, it also influences the design of production systems. Farmers' choices of GM products will depend on both the market structure for seeds and the market structure for other inputs. The situation will be different in cases when the same organization supplies both seed and the complementary input from cases when competitors supply the different inputs.

The late Kelvin Lancaster was the first to suggest that market goods embody multiple characteristics and that the value and productivity of a good depend on the composition of the user's activities (Lancaster, 1991). He also suggested that the value of market goods could be derived from and used to assess the value of its characteristics. Similarly, Sherman Rosen's hedonic pricing approach (Rosen, 1974) established a modeling framework to determine the value of a product's component characteristics within a market system. This approach was applied and expanded in the analysis of telecommunication and information markets. The Lancaster and Rosen approaches would provide powerful analyses of agricultural biotechnology markets, particularly because they allow the decomposition of a seed variety into a bundle of traits or characteristics which can be individually adjusted according to single or multiple (stacked) genetic modifications. The shape and heterogeneity of users' demands for particular characteristics (rather than for the composite good known as the "seed variety") may thereby explain otherwise unexpected patterns and impacts of GM adoption.

5.3 Introduction of New Agricultural Outputs and Grower Contracting

GM varieties that control pest problems either increase yield directly or serve to improve the effectiveness of other agricultural inputs in the production of traditional commodities. Our discussion of adoption above applies mostly to this type of GM product. However, innovations that drastically alter or improve agricultural output characteristics, for example, by increasing their contribution to nutrition or health, will lead to differentiated products, and their adoption may be associated with altogether different institutional arrangements. Farmers operating in a competitive environment may not be willing to adopt a new variety of tomatoes that look different and have different properties than existing ones, particularly if they are not confident that they will find a buyer. When it comes to a new GM variety that results in differentiated agricultural products, the developer of the new variety may be responsible for marketing the new product to the end-consumer. This is not unusual: contracting in the US poultry market was developed because of feed producers' need to supply secure output markets to buyers of their feed. During that time, poultry prices were not very stable, and the poultry market was not well established, so major feed companies stepped in and became marketers of poultry, which led to the evolution of the current structure in the poultry sector. Generally, among differentiated products, one may discover that developers of new products may contract with an intermediary for production but will then be responsible for final marketing.

When it comes to new GM varieties that lead to novel agricultural outputs, one may expect that they will be produced by farmers who work under contract with either the seller of the seed – who will also market the final product – or with other agribusiness companies that will assure an output market. Some of the major agribusiness and food companies, such as General Mills, Beatrice Foods, and Proctor & Gamble, may buy rights to GM varieties that produce new differentiated outputs, contract with farmers and sell the final products in their own brands to supermarkets. These types of activities will not be limited only to developed countries either; already agreements exist between agribusinesses in developed countries and growers in developing countries.

5.4 Acceptance of GM Varieties and Labeling of GM Products

Farmers' adoption of a biotechnology product will depend on their ability to sell output produced with GM varieties. It may be difficult or impossible to distinguish in a laboratory between milk produced by a cow that was injected with rBST and milk from a cow that was not, but consumers may nevertheless be concerned about how their food is prepared. That concern affects their willingness to purchase or pay for foods produced using certain technologies.

Biotechnology, indeed, is not the first case in which consumer preferences regarding food preparation and treatment have affected demand. For eons, human beings have held strong preferences over methods of food preparation for religious or ethical reasons. Economists do have the tools necessary to analyze consumers' food preferences with regards to biotechnology and the wider implications of those preferences. Studies suggest that one reason for the relatively widely held skepticism toward biotechnology products in Europe versus the United States is the lower trust in government statements regarding food safety in Europe. Heiman et al. (1999) showed that, in Israel, among individuals choosing between biotechnological or chemical solutions to an agricultural problem, a majority preferred biotechnology. The greatest opposition to biotechnology was among people who identified themselves as religious.

Demand research has to identify the basis upon which people make their choices regarding biotechnology. For instance, are consumers aware that there is a definite tradeoff between biological and chemical solutions to agricultural problems? It is important to assess the strength of consumers' objections to biotechnology and how they can be modified or reduced by technical or marketing changes. It is important to quantify consumer distaste toward the biotechnology product or, more specifically, toward the biotechnological characteristic of food products (in Lancaster's terms) and to compare this with quantification of their distaste toward the available alternative characteristics, such as those that result from chemical pesticides.[3] How much of a premium are people willing to pay for the hedonic qualities of "purity" or "naturalness"? Such terms must be defined carefully in order to quantify them, and, in so doing it may be possible to show that different segments of the consumer market define these terms quite differently. It is important to investigate such culturally laden consumer questions in both developed and developing country contexts.

A related issue that economists can help to resolve is the design of a labeling system. Economists play an important role in assessing the impact of labeling in other contexts. Economic research on both the cost of labeling and, more importantly, on the benefits of alternative forms of labeling, in terms of production and processing and in terms of consumer education, will be very useful and will enable a wider utilization of biotechnology. Answers to this type of study are context specific; therefore, the issues of labeling and information should be investigated in the context of both developed and developing nations.

6 ECONOMICS OF IPRs AND PUBLIC RESEARCH IN AGRICULTURAL BIOTECHNOLOGY

Finally, results from the ex ante economic analysis of new biotechnologies, which we have just discussed, is essential for another line of economic research aimed at the optimal design and management of IPRs and research institutions.

[3] An alternative way to characterize this dilemma is as a difference in perceptions between technology producers and food consumers about the nature of the biotechnology innovations. Producers may perceive and intend a new technology to be a simple, cost-reducing process innovation with no perceivable difference in output quality, aimed at a large market with relatively inelastic demand. Consumers may, on the other hand, in fact perceive the new technology as a "negative quality-enhancing" product innovation. This indeed is a dilemma in light of Spence (1975) who shows that gains (or losses) from quality improvements (product innovations) can be greater the more inelastic demand is in that market.

6.1 IPRs in Biotechnology

Economists are in a unique position to provide the knowledge base that will help policy-makers in the legal systems of all countries to establish institutions and laws for managing IPRs in biotechnology. As illustrated in Figure 2 above, IPRs impact decisions about which lines of research to pursue and which technologies to develop and commercialize. IPR protection should be designed to balance the gains from extra investments in R&D with higher prices, market concentration, and restriction of other R&D activities that may result from IPR protection. The performance of an IPR regime depends on its design and enforcement. If IPR protection for biotechnology is defined too narrowly, companies may underinvest or underdevelop agricultural biotechnology products from the point of view of social welfare. On the other hand, protection that is too broad may stifle competition and lead to a concentration of market power and unduly high prices. Also, as the methodologies of searching for new discoveries in biotechnology evolve, criteria for IPR protection will need to be modified. For example, even under the current state of knowledge, providing IPR protection for genomic discoveries – based solely on the deciphered composition or sequence of a random piece genetic material, without knowing its function and in hopes that it will turn out to constitute part of an important gene – does not make economic sense in terms of the incentives that it provides and the dampening effect it places on basic research. It is more reasonable to provide patent protection to functional genomic discoveries that identify the role of specific genes and that have implications for the design of new products.

The impact of an IPR regime obviously depends on the way rights are exercised by those who hold them. Suppose an organization holds all the patents for a particular process innovation (for example, how to modify a certain type of gene sequence). It may allow others to use the process in research in exchange for payment of a licensing fee, it may sell exclusive rights to use the patent in production, foregoing those rights itself, or it may simply sit on the rights to prevent others from using the innovation. Whichever strategy is taken by the organization, it will affect the evolution of that particular biotechnology. Because discoveries in biotechnology are made by many organizations and because there is much interdependence among firms, the industry may collectively choose to establish certain standards or protocols for IPR management. Here economists can play an important role in pointing out the tradeoffs among various approaches with alternative design mechanisms. Research regarding IPR policies is especially important since many of the discoveries and corresponding patents are issued to public research institutions. How should public research institutions design their licensing policy? Can they play a role in increasing efficiency by setting conditions that bar excessive restrictions on the rights to use innovations that were financed by the public sector? For example, access to process innovations or knowledge originating in the university likely ought not to be restricted, blocked, or exclusively licensed, but rather made available as long as users agree to pay competitive royalties.

6.2 Management of Biotechnology Research in Developing Countries and in the International Agricultural Research System

Most biotechnology innovations are discovered in developed countries and are designed to benefit agriculture in northern climates. There will likely be much less biotechnology research on diseases and crops specific to developing countries, especially by the private sector. Therefore, if biotechnological solutions are to meet the agricultural challenges of developing countries, economic research is needed to devise strategies to provide a knowledge base for biotechnology in developing nations. In particular, economists can help developing nations decide about the future of their national agricultural research, extension and distribution systems and help the international community to decide about the future of the international research centers that make up the Consultative Group on International Agricultural Research (CGIAR). For instance, what types of alliances should developing countries and government organizations form with private sector firms in developed nations? How should private sector biotechnology activities be regulated? To what extent can and will developing nations adopt IPR agreements developed largely by and for the developed world? How should they enforce IPR agreements? What concessions will they demand for enforcement?

A large body of literature, starting with Hayami and Ruttan's (1985) work, established the induced innovation hypothesis, which states that innovations are economic activities largely affected by economic incentives. Countries devote resources to develop technological innovations that overcome their constraints and save inputs they find scarce. Binswanger's (1974) induced innovation models suggest that optimal designs of research strategies have to take into account economic conditions and the expected productivities and costs of alternative research lines. Induced innovation models have been expanded to encompass research conducted by both public and private sectors. In general, the public sector engages in basic research with more public good properties, likely resulting in less-embodied innovations. The private sector often commercializes ideas originating in the public sector, or expands upon and further develops yet-unmarketable public knowledge into viable commercial products.

The extent to which research efforts in developed countries, especially in the private sector, address problems of developing nations depends on how the private sector views the potential of developing markets for products. Major research companies in developed countries are less likely to develop product lines for developing countries if potential users of these innovations cannot afford to pay for the products or if the companies are unable to secure IPRs or marketing channels to generate sufficient revenues from the sale of new products.

Biotechnology research in developing countries or the CGIAR likely requires investment in new equipment and intensive training of personnel. It may also entail more intensive use of the services of patent legal professionals and computerized databases to access information on patents filed and gene sequences discovered. The national research systems in developing countries have to design strategies to best serve their countries' interests and to get maximum returns on their research money. As such, their strategies must identify what benefits different lines of research can yield, particularly given the research activities in other countries and given their own ability to absorb knowledge and information and to adopt technologies from other sources.

Economic research is needed to analyze the tradeoff for developing countries between investing in different lines of basic research, versus simply obtaining rights to existing components of technology and refining and adopting them to local conditions. Economic analysis can identify the extent to which and the mechanisms by which the national agricultural research systems of developing countries ought to establish alliances with multinationals to access knowledge and intellectual property in return for providing multinationals with access to markets or to genetic resources and biodiversity. Economic analysis can help governments determine the extent to which their agricultural biotechnology research infrastructure should be integrated with research in other subfields of biotechnology, such as the medical sector, and the extent to which education and research activities in biotechnology should be integrated to take advantage of complementarities and increasing returns of scope.

Biotechnology may offer new opportunities for research cooperation. Alliances can, in theory, be formed in any combination or direction: between developing country governments and private organizations, between private and public research organizations, between developing countries, or between developed and developing countries. As the capacity to document and manipulate genetic materials increases, the value of knowledge on the functionality of genetic materials will increase greatly. In many cases, this knowledge requires analysis of the properties of species with a particular genetic makeup. Thus, biodiversity as a resource, knowledge of its genetic content, and its associated implications will grow in value over time. Since many of the landraces and exotic species are in developing countries, they may want to consider creating alliances with organizations in developed countries to upgrade their own capacity to conduct functional genomics and biodiversity research and to capture some of the benefits that it may yield. Bioprospecting agreements such as the one between Merck and a national park in Costa Rica are only early examples of much more elaborate arrangements that may evolve over time. The challenge that developing countries face is to develop arrangements that will capture the value added from the right combination of biological resources and biological knowledge and that will enhance their endogenous research capacity and knowledge base.

The CGIAR system is in itself a most creative institutional innovation and has played a major role in improving agricultural productivity in developing countries. It is an excellent example of a collective, almost global effort to conduct research and development activities having global implications. One of the major challenges facing this system is making the right institutional changes and the right research adjustments to biotechnology. The CGIAR has a strong program in traditional breeding and must now determine the value-maximizing management of research portfolios across the CGIAR centers so that resources will be allocated optimally between traditional breeding and biotechnology research. The two approaches of breeding and biotechnology are complementary under current conditions, and therefore each can be more valuable when they coexist in the same institution (Graff, 1999). Furthermore, these techniques will be gradually modified to incorporate new knowledge, and we expect the distinctions between breeding and biotechnology to blur significantly over time.

Foremost, the CGIAR must evaluate its IPR policy and determine what types of arrangements to pursue with private sector enterprises. This includes developing a well-defined and effective patent strategy, and deciding about royalty policies. Because of its past achievements and its shear size, the CGIAR has the moral authority and power to be an active participant in the global debate about the management of intellectual property rights in biotechnology.

As we argued earlier, with the evolution of biotechnology some types of knowledge will become more valuable, and the CGIAR should modify the portfolio of its activities accordingly. One important area to invest in is interdisciplinary efforts to design crop systems that integrate and harmonize the use of biotechnology-enabled traits and methods with traditional local inputs and other agroecologically sensible management systems in developing countries. The CGIAR may be most effective in developing methodologies and establishing principles for integrated crop management systems, given its interdisciplinary emphasis and its capacity to recognize constraints facing poor farmers. Emphasizing this line of research may require some reorganization of the CGIAR centers in order to shift attention from being focused on specific crops toward an emphasis on regional cropping systems. The CGIAR should emphasize existing research programs, initiate new efforts and develop research tools to study agroecological systems in developing countries: its objective would be to obtain data and develop methodologies to gain a better understanding of the function of various genetic materials and cropping systems within particular ecosystem contexts.

The gene banks maintained and managed by the CGIAR have been and continue to be major assets of this organization. Economic considerations play a major role in the reassessment and redesign of their organization as Wright and Koo (1999) among others have shown. The CGIAR system has to determine policies concerning access to its genetic materials and, in particular, to establish transparent arrangements with private-sector firms. The system has to establish optimal pricing schemes and agreements for the exchange of genetic knowledge and materials. If gene banks generate profits, how will they be allocated among the parties that have been paying to maintain the genetic resource? Or how will they be reinvested? There may be a need to invest in new research and maintenance activities to enhance abilities to capture knowledge from existing seed collections. Assessing the designs and options for organizations and institutions to carry out "best policies" is a typical challenge for economists.

As a major think tank in the economics of food, agriculture, and the environment in developing countries, the CGIAR has to be involved in economic research to develop policies that encourage the preservation of traditional agricultural and renewable resource production systems and natural habitats. Any benefits of biotechnology will be rendered less valuable without biodiversity, particularly insofar as diverse ecosystems will be a perpetual source of new knowledge and challenges. Biotechnology enhances the value of preserving biodiversity. However, under the current alignment of knowledge resources and institutions, parties in developed countries will gain much of the benefit resulting from biodiversity preservation activities. Economic theory suggests that special gainers should contribute to the maintenance of the systems enabling their gains. Designing appropriate transnational systems and institutions to support biodiversity is thus a major priority for economic research, and ought to be a major area of emphasis pursued by collective research organizations such as the CGIAR.

7 CONCLUSION

The evolution of biotechnology and its contribution to developing countries depend to a large extent on the availability of economic knowledge and on an adherence to economic principles in designing institutions and policies. Economic assessment and considerations ought to play a role in designing biotechnology policies, including those where religious, ethical and cultural considerations weigh heavily. Good economic analysis provides a reasonable assessment of the potential effects of proposed policy changes, and it suggests tools and mechanisms for managing the conflicts and trade-offs that are inevitable. However, to be effective, economists must work within an interdisciplinary framework. Basic biological and scientific knowledge are key inputs and constraints in the necessary economic models and the economists devising them should be outward looking – toward other disciplines and toward policy-makers – in their derivation of results and communication of outcomes. While rigor is essential in economics as in any other discipline, emphasizing rigor and methodological sophistication to the neglect of interdisciplinary interaction and communication will prevent economists from designing viable institutional policies to meet the biotechnology challenge facing developing agriculture. Some of the most important areas we have discussed where economic contributions may be most valuable include:

- developing criteria for allocation of resources for research funding and research priorities in the CGIAR and national research systems;
- developing new mechanisms for intellectual property rights and technology transfer in developing countries;
- designing crop production systems that incorporate biotechnology with other available inputs and agronomic practices;
- designing institutional arrangements for education and diffusion of biotechnology knowledge;
- researching and assessing attitudes toward biotechnology and design policies to address those attitudes;
- assessing diffusion and demand patterns for biotechnology products and designing appropriate pricing, marketing and extension mechanisms;
- assessing impacts that existing agricultural policy mechanisms will have on the introduction and diffusion of biotechnology and agricultural productivity and suggesting necessary policy reforms.

REFERENCES

Antle, J., and R. Just (1991): Effects of Commodity Program Structure on Resource Use and the Environment. In: R. Just, and N. Bockstael (eds.). *Commodity and Resource Policies in Agricultural Systems*. Agricultural Management and Economics Series, Springer, New York, pp. 97-128.

Binswanger, H. (1974): A Microeconomic Approach to Induced Innovation. *Economic Journal* 84 (336), pp. 940-958.

Castillo, F., D. Parker, and D. Zilberman (1999): The Performance of Offices of Technology Transfer. Department of Agricultural and Resource Economics, University of California, Berkeley.

Collender, R., and D. Zilberman (1985): Land Allocation Under Uncertainty for Alternative Specifications of Return Distributions. *American Journal of Agricultural Economics* 67 (4), pp. 779-786.

David, P., B. Hall, and A. Toole (1999): Is Public R&D a Complement or Substitute for Private R&D? A Review of the Econometric Evidence. Working Paper 7373, National Bureau of Economic Research, Cambridge, MA.

Encaoua, D. (1998): The Economics and Econometrics of Innovation. *Annales D'Economie et de Statistique* 49/50, pp. 27-51.

Feder, G., R. Just, and D. Zilberman (1985): Adoption of Agricultural Innovations in Developing Countries: A Survey. *Economic Development and Cultural Change* 32 (2), pp. 255-298.

Foltz, J., J. Lee, M. Martin, and P. Preckel (1995): Multiattribute Assessment of Alternative Cropping Systems. *American Journal of Agricultural Economics* 77 (2), pp. 408-420.

Graff, G., G. Rausser, and A. Small (1999): Agricultural Biotechnology's Complementary Intellectual Assets. Paper presented at the conference "The Shape of the Coming Agricultural Biotechnology Transformation" 17-19 June, Tor Vergata University, Rome.

Green, G., and D. Sunding (1997): Land Allocation, Soil Quality, and the Demand for Irrigation Technology. *Journal of Agricultural and Resource Economics* 22 (2), pp. 367-375.

Griliches, Z., B. Hall, and A. Pakes (1987): The Value of Patents as Indicators of Inventive Activity. In: P. Dasgupta, and P. Stoneman (eds.). *Economic Policy and Technological Performance*. Cambridge University Press, Cambridge, pp. 97-124.

Hayami, Y., and V. Ruttan (1985): *Agricultural Development: An International Perspective*. Johns Hopkins University Press, Baltimore.

Heiman A., D. Just, and D. Zilberman (1999): The Role of Socio-Economic Factors and Lifestyle Variables on Attitude Toward and Demand for Genetically Modified Foods. Department of Agricultural and Resource Economics, University of California, Berkeley.

Hochman, E., and D. Zilberman (1978): Examination of Environmental Policies Using Production and Pollution Microparameter Distributions. *Econometrica* 46 (4), pp. 739-760.

Howitt, R. (1995): A Calibration Method for Agricultural Economic Production Models. *Journal of Agricultural Economics* 46 (2), pp. 147-159.

James, C. (1998): Global Review of Commercialized Transgenic Crops. ISAAA Briefs, No. 8, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

de Janvry, A., G. Graff, E. Sadoulet, and D. Zilberman (1999): Agricultural Biotechnology and Poverty: Can the Potential Be Made a Reality? Paper presented at the conference "The Shape of the Coming Agricultural Biotechnology Transformation", 17-19 June, Tor Vergata University, Rome.

de Janvry, A. and E. Sadoulet (1992): Agricultural Trade Liberalization and Low Income Countries: A General Equilibrium-Multimarket Approach. *American Journal of Agricultural Economics* 74 (2), pp. 268-280.

Just, R., and D. Zilberman (1983): Stochastic Structure, Farm Size, and Technology Adoption in Developing Agriculture. *Oxford Economic Papers* 35 (2), pp. 307-328.

Lancaster, K. (1991): A New Approach to Consumer Theory. In: K. Lancaster (ed.). *Modern Consumer Theory*. Elgar, Aldershot, UK and Brookfield, Vt. pp. 11-43, (previously published in 1966).

Mansfield, E. (1961): Technical Change and the Rate of Imitation. *Econometrica* 29 (4), pp. 741-766.

Mowery, D., and N. Rosenberg (1979): The Influence of Market Demand Upon Innovation: A Critical Review of Some Recent Empirical Studies. *Research Policy* 8, pp. 102-153.

Osgood, D. (1999): Information, Precision, and Waste. Ph.D. thesis, University of California, Department of Agricultural and Resource Economics, Berkeley.

Parker, D., and D. Zilberman (1993): University Technology Transfers: Impacts on Local and U.S. Economies. *Contemporary Policy Issues* XI, pp. 87-99.

Pisano, G. (1988): Innovation Through Markets, Hierarchies, and Joint Ventures : Technology Strategy and Collaborative Arrangements in the Biotechnology Industry. Ph.D. thesis, University of California, School of Business, Berkeley.

Postlewait A., D. Parker, and D. Zilberman (1993): The Advent of Biotechnology and Technology Transfer in Agriculture. *Technological Forecasting and Social Change* 43, pp. 271-287.

Rausser, G. (1999): Public-Private Alliances. *AgBioForum* 2 (1), pp. 5-10.

Rausser, G., and A. Small (1996): The Economic Value of Patents, Licenses, and Plant Variety Protection. Working Paper No. 797, Department of Agricultural and Resource Economics, University of California, Berkeley.

Rosen, S. (1974): Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition. *Journal of Political Economy* 82 (1), pp. 34-55.

Scherer, F. (1965): Firm Size, Market Structure, Opportunity, and the Output of Patented Inventions. *American Economic Review* 55, pp. 1097-1123.

Shah, F., D. Zilberman, and U. Chakravorty (1995): Technology Adoption in the Presence of an Exhaustible Resource: The Case of Groundwater Extraction. *American Journal of Agricultural Economics* 77 (2), pp. 291-299.

Spence, A. (1975): Monopoly, Quality, and Regulation. *Bell Journal of Economics* 6 (2), pp. 417-429.

Sunding, D., and D. Zilberman (2000): The Agricultural Innovation Process: Research and Technology Adoption in a Changing Agricultural Sector. In: .B. Gardner, and G. Rausser (eds.). *The Handbook of Agricultural Economics*. Elsevier, forthcoming.

Taylor, R., and R. Howitt (1993): Aggregate Evaluation Concepts and Models. In: Carlson, D. Zilberman, and Miranowski (eds.). *Agricultural and Environmental Resource Economics*. Biological Resource Management Series, Oxford University Press, New York, pp. 142-74.

Teece, D. (1986): Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing, and Public Policy. *Research Policy* 15, pp. 285-305.

Williams, J.R., P.T. Dyke, and C.A. Jones (1983): EPIC – A Model for Assessing the Effects of Erosion on Soil Productivity. In: W.K. Lauenroth, G.V. Skogerboe, and M. Flug (eds.). *Analysis of Ecological Systems: State-of-the-Art in Ecological Modeling*. Elsevier, New York, pp. 553-572.

Wright, B. (1983): The Economics of Invention Incentives: Patents, Prizes, and Research Contracts. *American Economic Review* 73 (4), pp. 691-707.

Wright, B., and B. Koo (1999): The Effects of Advances in Biotechnology on the Optimality of Ex-Ante Evaluation of Genebank Material. Presented at the conference "The Shape of the Coming Agricultural Biotechnology Transformation", 17-19 June, Tor Vergata University, Rome.

Chapter 9

WELFARE PROSPECTS OF TRANSGENIC CROPS IN DEVELOPING COUNTRIES

Matin Qaim

Abstract: This paper describes an ex ante analytical framework that can assist in analyzing the potential welfare impacts of specified crop biotechnologies in developing countries. In a case-study approach, the expected effects of virus- and weevil-resistant sweetpotatoes in Kenya and of virus-resistant potatoes in Mexico are scrutinized. Built upon recombinant methods, these technologies are being developed within joint public-private sector research initiatives. The resulting applications will be released in the near future and, because traditional cultivation practices do not need to be altered, they will easily be integrated into existing farming systems. The quantitative results indicate that the innovations are likely to bring about significant welfare gains for agricultural producers and consumers. These examples confirm that biotechnology can offer cost-effective solutions to a wide range of agricultural and food problems in developing countries. To actualize this potential in a broader context, however, requires decisive policy support at national and international levels.

1 INTRODUCTION

Modern agricultural biotechnology is a hotly debated topic in the international development community. Apart from environmental and health effects, the socioeconomic implications of transgenic technology are an especial subject of acute controversy. On the one hand, some technocrats portray biotechnology as the key to the world's hunger and poverty problems. Outspoken critics, on the other hand, believe that high-tech is per se inappropriate for low-income countries. They fear that the sophisticated tools of genetic engineering would overstrain the scientific and regulatory capacity of most developing countries. Furthermore, these critics argue that investments in biotechnology would be a misallocation of scarce research

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funds, which would reinforce existing national and international power imbalances. For opponents, the controversy surrounding the so-called “Terminator” and “Traitor” technologies particularly fueled the notion that biotechnology does not promise improvement but poses a threat to global food security (RAFI, 1999). Such extreme arguments, however, often fail to see that a new technology is neither a boon nor a bane in itself. Biotechnology has great promises to contribute to sustainable agricultural development. But this will only happen if there are appropriate institutional and policy frameworks to ensure that biotechnology does not discriminate against the poor. Such frameworks are at least as important as the technology-inherent parameters themselves.

At the international level, biotechnological advances are primarily driven by transnational companies that produce seed innovations to satisfy the market (James, 1999; ODI, 1999). The economic risks of developing commercial applications designed for small-scale farmers in the South are usually too high. Public institutes, on the other hand, find it increasingly difficult to conduct independent research because the private sector owns most of the relevant patents (cf. Cohen et al., 1998; de Janvry et al., 1999). To provide suitable technologies to the poor, institutional adjustments must be made in the international agricultural research system. In particular, viable models of research partnerships between the public and the private sector need to be identified. Furthermore, imperfections in developing countries’ markets for agricultural inputs and outputs make it difficult for resource-poor farmers to participate in new technological developments, as the green revolution partly demonstrated. Fortunately, genetically engineered crops – notably those with transgenic mechanisms for stress resistance – differ from green-revolution technologies in that they do not require complementary inputs. In fact, these new crops can be tailored to meet the specific needs of farmers in remote areas cultivating in marginal agroecological conditions. Market imperfections, therefore, are not as large an obstacle for transgenic crops, but they must still be addressed.

To-date, empirical evidence about the actual impacts of transgenic crops on small-scale farmers and food consumers in developing countries is scant. The loud international debate is too often grounded on beliefs rather than facts. If we want to learn from the past and avoid the undesired equity effects of new technologies, we need timely information to help us formulate appropriate policies. The present paper tries to make a small contribution to this much-needed research. It briefly describes an ex ante analytical framework that can help analyze the welfare effects of specific crop biotechnologies in developing countries (section 2). This framework is applied to two country case studies. The first example (section 3) explores the impacts of transgenic virus- and weevil-resistant sweetpotato varieties in

Kenya. Sweetpotato is an interesting commodity from a food security perspective, because in Africa it is predominantly produced and consumed by the poor population segments. The second example (section 4) scrutinizes the potential effects of transgenic virus-resistant potatoes in Mexico. All technologies analyzed are being developed through international collaborative efforts that involve both the public and the private sector. The innovations will be released in the next few years. The concluding section discusses some general implications of the case-study results.

2 ANALYTICAL FRAMEWORK

2.1 Methodology

The welfare effects of the different transgenic technologies are analyzed by changes in economic surplus measures. These are modeled in a partial equilibrium framework of the respective commodity market. Although this approach neglects the positive technology-induced spillover effects to other markets and sectors, it is the most commonly used methodology for economic assessments of crop-related innovations (Alston et al., 1995). The supply and demand functions are assumed to be linear curves. Little is known about the true shape of the curves, but Zhao et al. (1997) showed that errors of functional misspecification often have only minor effects on the change in economic surplus. Biotechnological progress will cause the commodity supply curve to shift downwards by a factor of K, which is defined as the potential per unit cost reduction of the technology, multiplied by the innovation adoption rate. The shift of the supply curve is modeled in a parallel way. This is a logical conjecture, because there is no reason to expect that farmers with high marginal costs of production would realize progress rates that are different from those realized by the low cost producers.

For sweetpotatoes in Kenya, the model is refined to account for home consumption in the producing households (the commodity is produced on a semi-subsistence basis). Hayami and Herdt (1977) proposed to introduce a vertical curve for home consumption. Then the price-inelastic, home-consumed quantity (q^{home}), together with the price-elastic market demand (q^{market}), adds up to the total quantity demanded (q). At equilibrium price (p) this demanded quantity equals the total quantity produced. Thus, the annual changes in producer surplus (ΔPS) and in consumer surplus (ΔCS) can be calculated as (cf. Qaim, 1999a):

(1) $$\Delta PS = p \cdot q \cdot \left(\frac{dp}{p} + K \right) \cdot \left(1 + 0.5 \cdot \varepsilon_s \cdot \left(\frac{dp}{p} + K \right) \right) + (-dp \cdot q \cdot h),$$

(2) $$\Delta CS = -p \cdot q \cdot \frac{dp}{p} \cdot \left(1 + 0.5 \cdot \varepsilon_d \cdot \frac{dp}{p} \right) - (-dp \cdot q \cdot h),$$

where h is the share of home consumption in total production. ε_s and ε_d are the price elasticities of supply and demand, respectively.

Home consumption of potatoes is negligible in Mexico. Significantly, however, different production conditions occur between small- and large-scale farmers. In order to analyze the distribution effects of the transgenic technology, we disaggregate the domestic potato supply curve into the partial supply functions of n producer groups of different farm sizes. This procedure builds up on an approach by Davis et al. (1987), who used market segmentation in a geographical sense. We restrict the disaggregation procedure to the supply side (s), so that all farm groups are facing the same aggregate demand curve (d) (cf. Qaim, 1999b). Market clearing is defined as:

(3) $$\sum_{i=1}^{n} q_{s,i}(p) = q_d(p).$$

The changes in the economic surplus measures can be calculated as outlined in equations (1) and (2), whereby:

(4) $$\Delta PS = \sum_{i=1}^{n} \Delta PS_i \ .$$

The models for Kenya and Mexico are run separately for the individual technologies, and welfare measures are derived on an annual basis for a period of 16 years after the release of the technology. Results are summarized in present value annuity figures, which are calculated using a discount rate of 10 percent. Exogenous growth in demand during the period of consideration is accounted for by letting the demand curve shift rightwards by the average annual population growth rate in each country.

2.2 Data Acquisition

The market-related data necessary to run the models (equilibrium prices, quantities, elasticity coefficients, etc.) have been obtained primarily from official agricultural statistics and published literature sources. The specification of the technology shift factor K, however, is not a straightforward procedure in the ex ante setting. None of the transgenic technologies analyzed has so far been released for commercial application, and so possible per unit cost reductions under farmers' conditions and innovation adoption rates cannot yet be observed. Accordingly, different interview surveys were conducted in 1998 to come up with realistic assumptions for the technology-related parameters. First, a number of researchers working on the crops of interest were asked for their personal technology assessments. Many of these researchers were directly involved in the particular biotechnology research projects, but completely independent researchers were also contacted to exclude possible information bias (cf. Qaim and von Braun, 1998). Information about the present "pre-technology" situation at the farm level was acquired through semi-structured interviews with agricultural producers in the main growing regions of Kenya and Mexico, supplemented by discussions with agricultural extensionists in the respective locations. The farm-level data are needed to translate the researchers' statements into sound economic information. Moreover, this data allowed for a better understanding of crop production systems and helped to identify reasonable future technology adoption rates and possible dissemination constraints.

3 TRANSGENIC SWEETPOTATOES IN KENYA

3.1 Sweetpotato Farming Systems

Spread over various agroecological regions, around 2 percent (75,000 hectares) of the total arable land in Kenya is cultivated with sweetpotato, which is predominantly grown on small and resource-poor farms. Cropping patterns typically embrace a large number of activities, including the cultivation of other staple food crops, fruits, vegetables and some export commodities. The average size of a sweetpotato-producing farm in the sample is 2.3 hectares, of which the mean sweetpotato holding is about 0.16 hectares. Most of the farmers grow two sweetpotato cycles per year, the first in the long rainy season and the second during the short rains. Sweetpotato is often an insurance crop because it yields comparatively well under adverse environmental conditions. Purchased inputs are rarely used. Taking into account the opportunity cost of family labor, the mean production cost per ton of sweetpotato amounts to US $35. Women primarily manage the crop, and on average producing households directly consume some 40 percent of the harvest. Surplus cash revenues are usually spent on basic food and non-food items to meet the immediate needs of the family.

Compared to other sweetpotato-producing regions in the world, Kenya's average yield level of 9.8 tons per hectare is fairly low. Despite the crop's robustness, farmers suffer significant yield losses caused by biotic stresses. The most important disease is the sweetpotato virus disease (SPVD), a complex of different virus types. Sweetpotato researchers interviewed in Kenya estimated average crop losses due to viruses at 12 percent. Losses are somewhat higher in the moist western part of the country than in the drier central and eastern parts. Sweetpotato weevils compound the problem, reducing yield levels by 20 percent on average. Currently, there are no efficient methods to control viruses and weevils in sweetpotato, partly because the crop has been neglected for a long time by national and international agricultural research (Jansson and Raman, 1991). Although in recent years traditional breeding programs for virus resistance have produced the first acceptable clones, it is quite complicated to combine this resistance trait with other desired quantity and quality characteristics in one sweetpotato variety. Furthermore, weevil resistance has so far been impossible to obtain using a conventional breeding approach (Carey et al., 1997). A promising course to raise sweetpotato yields in farmers' fields, therefore, would be to expand the conventional toolbox with biotechnological methods.

3.2 The Biotechnology Projects

A research project to advance non-conventional virus resistance in sweetpotato was launched in 1992 by the private US company Monsanto and the Kenya Agricultural Research Institute (KARI).[1] The project's initial phase was co-sponsored by the United States Agency for International Development (USAID). In cooperation with KARI scientists, basic research components of the project – such as the development of suitable biotransformation and plant regeneration protocols – have been carried out in Monsanto's USA laboratories (Wambugu, 1996). The transfer of the recombinant sweetpotato technology from USA to Kenya took place in 1999. A royalty-free licensing agreement with Monsanto has been signed, which allows KARI to use the technology and to share it with other African countries in the future. The project's next phase began in 1999. Sponsored through the Agricultural Research Fund (ARF), this new phase is institutionally supported by Monsanto, the International Service for the Acquisition of Agri-biotech Applications (ISAAA), and the International Potato Center (CIP). In this part of the project, virus-resistant sweetpotatoes in Kenya will be field-tested and transgenic varieties subsequently released. This is Kenya's initial experience with bioengineered crops. Accordingly, building capacity in safe technology use is an integral part of the project's

[1] The research builds upon the sweet potato feathery mottle virus (SPFMV) coat protein. Because SPFMV appears to be the dominant virus in the SPVD complex, there is a high probability that major virus problems in Kenya can be controlled with this mechanism.

activities. The first transgenic variety could be distributed to Kenya's sweetpotato farmers in 2002. At the same time, KARI will transform additional varieties for virus resistance in its newly refurbished biotechnology laboratory.

Research is also underway to develop transgenic weevil resistance for sweetpotato in Africa. These efforts involve various public organizations that use *Bacillus thuringiensis* (*Bt*) genes patented by various private companies. Given its experience with the Monsanto/KARI project, Kenya is expected to be one of the first countries where the sweetpotato weevil resistance technology will be deployed, possibly from 2004 onwards. The environmental and health risks of both technologies are considered to be low. For a more detailed discussion of risks and of the possibility of resistance development in pathogen populations see Qaim (1999a).

3.3 Technology Shift Factors

The algebraic formulations of the market model showed that the supply curve's shift factor K is a pivotal variable for the evaluation of the biotechnology applications. As the expected effects of virus-resistant varieties are different from those of weevil-resistant ones, K has to be specified separately for both technologies. Relevant parameters are shown in Table 1. The potential yield increases are translations from the yield losses stated earlier. But for the virus resistance technology an additional aspect needed to be considered, since farmers in high virus pressure areas often use sweetpotato clones that have a certain degree of natural resistance to viruses. This makes direct crop losses rather low. The trait of natural virus resistance, however, is usually negatively correlated with the yield potential. This circumstance also complicates conventional crossbreeding. Therefore, a specific advantage of genetic engineering is that higher-yielding but naturally susceptible clones can be endowed with transgenic virus resistance that would further raise average yield levels. The potential per unit cost reductions have been derived by comparing farm-level crop enterprise budgets without and – hypothetically – with the use of the transgenic technologies. It must be stressed that the two technologies will not be released simultaneously. The first transgenic virus-resistant varieties could become available to farmers as early as 2002, while the weevil-resistant varieties will not be released before 2004.

Technology adoption is generally a function of the expected profitability and perceived risk aspects associated with an innovation. For both sweetpotato technologies the adoption risk is comparatively low. Once released by KARI, the transgenic germplasm will quickly penetrate the

Table 1: Expected agronomic effects and technology adoption rates of transgenic sweetpotato technologies in Kenya

	Virus resistance	Weevil resistance
Potential yield increase (percent)	18	25
Potential per unit cost reduction (percent)	16	20
Maximum adoption (years after release)	6	5
Maximum adoption rate (percent)	38	50

existing informal markets for sweetpotato vines, which farmers use for planting material. They can reproduce the germplasm themselves, moreover, and there is no need for them to adjust their traditional cropping practices. Due to these simple dissemination mechanisms, a linear adoption profile is assumed. The speed and maximum degree of technology adoption, however, will hinge on the number of transformed varieties. This is because varietal preferences among farmers are fairly diverse, especially with respect to taste characteristics. For the purpose of this analysis, it is assumed that the technologies will be incorporated into at least five different varieties.

3.4 Welfare Impacts

This section presents the results of the model computations based on the outlined information. International trade with sweetpotato is negligible, so Kenya can be considered a closed economy. The price elasticity of sweetpotato demand is assumed to be –0.4, whereas the price elasticity of supply is 0.3. The annuities of the changes in economic surplus caused by the two transgenic technologies are summarized in Table 2.

It is obvious that the two innovations are likely to bring about substantial welfare gains in Kenya. Although the aggregate advantage of the weevil-resistant varieties is expected to be higher than that of the virus-resistant ones, this comparison should not be misunderstood as a priority setting exercise. In the future, both resistance mechanisms will become available, possibly even incorporated into the same varieties.

Sweetpotato-producing households will be the main beneficiaries (remember that the benefits through subsistence consumption are covered on the producer side). Rising in-kind and in-cash revenues will improve the food situation of rural households. This could especially hold true because sweetpotato incomes are usually controlled by women, who often have a higher propensity to invest more in household welfare-increasing activities than men (cf. von Braun and Kennedy, 1994). Market consumers will also profit substantially from falling sweetpotato prices caused by productivity

Table 2: Projected annual welfare gains of transgenic sweetpotato technologies in Kenya

	Virus resistance	Weevil resistance
Total gain in economic surplus (million US$)	5.4	9.9
of which		
Producers (percent)	74	74
Consumers (percent)	26	26

increases. Since sweetpotato is expected to be a slightly inferior commodity (cf. Omosa, 1997), poor urban consumers will gain more than the richer ones, both in relative and absolute terms. Greater commercialization of sweetpotato cultivation can be expected due to Kenya's ongoing urbanization, and such a higher market integration of sweetpotato production would further expand consumers' benefits.

Given the scarcity of financial resources, technological benefits always have to be weighed up against the costs of research and development (R&D). Accordingly, detailed cost data have been assembled for the virus resistance project. In the cost-benefit analysis for this project we consider the expenditures for all organizations involved in applied research, local capacity building in Kenya (including the establishment of a biotransformation laboratory and of biosafety regulations), technology transfer and project overheads. The more basic research costs borne by Monsanto are not accounted for. Monsanto will not use the technology commercially, but it will be transferred to a number of other African countries, which makes it inappropriate to impose the full research cost on Kenya. Respecting the research lag, an internal rate of return (IRR) of 60 percent is derived for the virus resistance project.

Detailed cost data for the weevil resistance technology could not be collected as the underlying research initiatives are in an earlier phase. It is expected that costs will be lower than those of the virus project because of already existing experiences with recombinant sweetpotatoes and *Bt*-technology. Nonetheless, to stay on the cautious side, we assume the same costs for both innovations, which obtains an IRR of 77 percent for the weevil resistance technology. These figures clearly indicate that modern biotechnology can offer promising and cost-effective solutions to the problems of poor farmers and food consumers in developing countries.

4 TRANSGENIC POTATOES IN MEXICO

4.1 Potato Farming Systems

In Mexico, potato is more a horticultural commodity than a staple food crop. It is grown on 63,000 hectares, approximately 0.5 percent of the country's total arable land. Most of the overall production (70%) is consumed as fresh tubers; comparatively little is processed. The crop is grown in 24 of Mexico's 32 states, in some areas in two seasons per year. Owing to the distinct climatic conditions, phytosanitary problems can be severe. The most pressing disease is potato late blight, caused by a fungus. But viruses also cause significant yield losses, and conventional resistance breeding has so far had only limited success (cf. Ghislain et al., 1997).

A clear North-South gradient can be discerned in production conditions. In northern Mexico, potatoes are predominantly grown by large-scale farmers using advanced technologies, including irrigation. In the central and southern regions, by contrast, there are also many small-scale and resource-poor farmers engaged in potato production, and they are often located in high altitudes. Given this heterogeneity of potato farming systems, it is instructive to further disaggregate the group of producers. As indicated earlier, we differentiate between three groups of different farm sizes to analyze the technology's distribution effects:

- small-scale farmers, with a potato area of less than 5 hectares,
- medium-scale farmers, with between 5 and 20 hectares, and
- large-scale farmers, with a potato holding of more than 20 hectares.

The potato area of a Mexican farm is closely correlated with the total farm size and other important socioeconomic variables (cf. Biarnès et al., 1995). Home-consumed shares are negligible for all three farm types. Potato is a fully commercialized crop, and even smallholders use remarkable amounts of purchased inputs. Table 3 shows some group characteristics derived from the interview surveys.

The divergent production practices are reflected by the big differences in production costs and yield levels obtained per unit area. Most of the variance is due to differing outlays for farm chemicals: larger farms use substantial amounts of fertilizers and pesticides. Cost differences also occur because of different sources of tuber seeds. Large-scale producers regularly purchase certified seeds, but small- and medium-scale farmers predominantly use farm-saved seeds or obtain their planting material on informal markets from

Table 3: Characteristics of different potato farm types in Mexico

	Small-scale	Medium-scale	Large-scale
Share of total production (percent)	12	24	64
Production cost (US$/ha)	1,417	2,560	4,174
Yield (t/ha)	11.1	20.9	31.8
Per unit production cost (US$/t)	128	122	131
Virus-induced yield losses (percent)	35	25	15
Price elasticity of supply	0.3	0.4	0.5

neighboring farmers.[2] Viruses are transmitted through infected tuber seeds, so larger farms have lower virus-induced crop losses because they plant better quality seeds. Interestingly, the per unit costs of production are almost identical for all three farm types (this comparison, however, only refers to the variable cost of potato production).

4.2 The Biotechnology Project

In 1991, a collaborative project between Monsanto and Mexico was undertaken to make transgenic virus-resistant potatoes available to Mexican farmers. This project differs from the sweetpotato projects discussed above in that the basic technology was not developed specifically for developing countries. Instead, the project builds upon proven technology already commercialized by Monsanto in the USA. Brokered by ISAAA and financially supported by the Rockefeller Foundation, the project began with Monsanto's donation of coat protein technology conferring resistance to two different potato viruses, potato virus X (PVX) and potato virus Y (PVY). The Center for Research and Advanced Studies (CINVESTAV), a public Mexican institute, undertook the adaptation of this technology to local requirements (cf. Rivera-Bustamante, 1995). Different transgenic varieties have been field-tested since the mid-1990s in collaboration with the National Institute for Agricultural Research (INIFAP). This is the first transgenic end-technology developed by national organizations in Mexico, so building capacity in R&D as well as in biosafety regulations is an integral part of the project. With Monsanto's donation of replicase technology for resistance to the potato leafroll virus (PLRV), a new phase of the project began in 1997. PLRV resistance is currently being integrated into the same varieties earlier transformed for resistance to PVX and PVY, and varieties with resistance to all three virus types could become available for Mexican farmers in 2002. Economically, PRLV is much more important than PVX and PVY, and the

[2] Certified potato tuber seeds are 75 percent more expensive than the tubers obtained form informal markets on average.

combined resistance mechanisms are expected to reduce virus-induced crop losses by 85 percent or more. Technological peculiarities are discussed in greater detail by Qaim (1999b).

Unlike the Kenyan sweetpotato projects, in which the recombinant technologies can be applied to any sweetpotato clone, the potato virus technologies in Mexico are subject to a detailed contractual agreement with Monsanto that allows for the transformation of only a restricted list of potato varieties. This is because Monsanto itself has already released the technology in the USA and might wish to commercialize it in Mexico and other countries in the future, especially in connection with certain popular processing varieties. An unrestricted license to Mexico could, therefore, contradict Monsanto's own business interests. Given the greater economic importance of PLRV, the permission to use the replicase technology is confined to fewer varieties than the coat protein technology. Monsanto's approval to use and commercialize the replicase technology in Mexico's most popular potato variety, Alpha, is still pending. For the purpose of this analysis it is assumed that an agreement will be reached in the near future.

4.3 Technology Shift Factors

The expected agronomic effects and technology adoption rates of transgenic virus-resistant potatoes are shown in Table 4. The figures are based on the interview surveys in Mexico. Strikingly, the potential yield gains and per unit cost reductions are significantly higher for the smaller than for the larger farms. This is due, as mentioned above, to lower virus crop losses for large-scale producers who purchase certified seeds.

Technology adoption in Mexico is presumed to follow a linear profile similar to that for Kenyan sweetpotatoes. All farm types can use the virus-resistant varieties without the need to adjust the traditional input mix, and the transgenic material will be disseminated via existing markets for certified seeds. Although the small- and medium-scale potato producers rarely purchase certified seeds, after a certain time lag informal markets will also be penetrated with transgenic germplasm. This farmer-to-farmer dissemination mechanism will work at least for those varieties used by both small- and large-scale farmers. Yet to avoid fungicide applications, 69 percent of the smallholders and 27 percent of the medium-scale farmers use certain red-colored varieties with a natural resistance to potato late blight; these varieties are not used by the large-scale farmers for quality reasons. CINVESTAV is transforming these red-colored varieties for virus resistance, but a dissemination constraint is expected because the link between formal seed markets and smaller farms is missing. This is reflected in the small- and

Table 4: Expected agronomic effects and technology adoption rates of transgenic potato virus resistance in Mexico

	Small-scale	Medium-scale	Large-scale
Potential yield increase (percent)	46	28	15
Potential per unit cost reduction (percent)	32	22	13
	Adoption under the present institutional situation		
Maximum adoption (years after release)	9	7	3
Maximum adoption rate (percent)	30	51	71
	Adoption with improved access for smallholders		
Maximum adoption (years after release)	7	7	3
Maximum adoption rate (percent)	99	78	71

medium-scale farmers' lower adoption rates under the present institutional arrangements (see Table 4). Technology access for the smallholders could be improved, however, by targeted institutional adjustments. One option would be to subsidize the certified transgenic seeds of the red-colored varieties. After having received subsidized access to formal seed markets once, the farmers could easily reproduce the virus-resistant germplasm on their own. Correspondingly, the adoption rates would improve tremendously, as Table 4 makes clear.

In total, the adoption rates for transgenic potatoes in Mexico will be higher than for transgenic sweetpotatoes in Kenya because only a limited number of preferred potato varieties are used by the producers (i.e., varietal diversity is lower). For instance, the potato variety Alpha alone accounts for 60 percent of Mexico's overall potato production.

4.4 Welfare Impacts

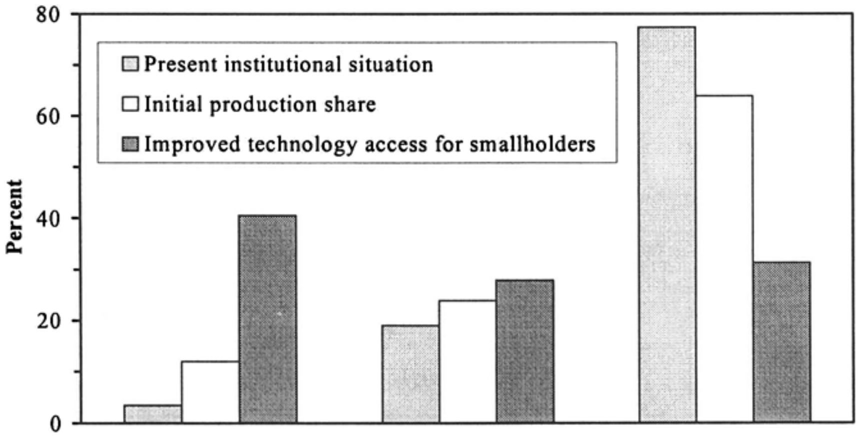
The welfare effects of transgenic virus-resistant potatoes in Mexico are analyzed under the assumption of a closed potato economy. To date, the internationally traded potato amounts are small due to high import tariffs (217 percent in 1999). Although barriers to trade are gradually being reduced under the North American Free Trade Agreement (NAFTA), different consumer preferences in the USA and Mexico could hamper a significant increase in potato trade flows. Currently, the aggregate potato demand curve in Mexico is downward sloping with a price elasticity of –0.4 (Qaim, 1999b). Table 5 summarizes the annuities of the changes in economic surplus created by biotechnology in Mexican potatoes.

Table 5: Projected annual welfare gains of transgenic potato virus resistance in Mexico

	Present institutional situation	Improved technology access for smallholders
Total gain in economic surplus (million US$)	30.3	45.1
of which		
Producers (percent)	46	51
Consumers (percent)	54	49

Two scenarios are shown. The first extrapolates from current seed distribution mechanisms; the second assumes improved technology access for smallholders (see previous sub-section). Both scenarios reveal substantial welfare gains for Mexican potato producers and consumers.[3] Total gains, however, are 50 percent higher under the assumption of a seed subsidy for the transgenic varieties exclusively used by the smallholders. Apart from these aggregate impacts, we also want to know who among the producers stands to benefit the most. The disaggregation of the supply curve (described above) allows for the analysis of such distribution implications. These are shown graphically in Figure 1.

Figure 1: Distribution of producer benefits among farm groups in Mexico



[3] The possibility of expanded international trade in the future was also tested. Although the change in consumer surplus shrinks, the general statements remain unaffected.

Despite the tremendous potential of these technologies for small-scale farmers, they have only a marginal share in the benefits under the present institutional situation. By far the biggest proportion of the total change in producer surplus would go to large-scale potato growers. Furthermore, by comparing the distribution of the benefits with the farm groups' initial production shares, it becomes obvious that the technology could lead to increased income concentration. Appropriate policies, however, could prevent this. Implementing the proposed seed subsidy or similar support mechanisms to facilitate smallholders' access to the technology would actually improve income distribution in the Mexican potato sector. This example underscores the importance of disaggregate policy analyses for heterogeneous target groups of biotechnology applications.

Benefit-cost relationships are calculated based on a detailed account of investments by the different organizations involved in the potato virus resistance project. As in the Kenyan example, the basic research cost borne by Monsanto is not considered for the biotechnology transfer to Mexico. This is justified since Monsanto is also commercializing the potato technology in other countries. So the contemplated cost items include the investments for laboratory refurbishment in Mexico, technology adaptation, capacity- and institution building for safe technology deployment and administrative overheads. An IRR of 54 percent is derived for the present institutional situation scenario. For the improved technology access scenario, the additional expenditure for policy support mechanisms must also be included. We therefore conducted a rough calculation of the cost of establishing a national seed subsidy. In spite of fairly conservative assumptions, we obtain an IRR of 58 percent. This figure shows that the proposed institutional adjustment in the seed distribution system would not only improve the technology's equity effects, but would also improve the project's overall efficiency at the same time.

5 CONCLUSION

The case studies from Kenya and Mexico emphasize the high benefit potentials of genetic engineering for poor agricultural producers and consumers in developing countries. Although the development of modern biotechnologies can be quite demanding at the laboratory stage, this does not hold for the resulting end-technologies, the genetically engineered crop varieties that farmers deploy. Transgenic crops, especially those with resistance to biotic and abiotic stress factors, fit well into small-scale farming systems and can easily be integrated without adjusting traditional cropping practices. The comparatively low setup cost for adopting genetically engineered technologies at the farm level also makes this technology useful for semi-subsistence agriculture. Furthermore, because women often control the incomes of semi-subsistence crops, improving the productivity of these crops through modern biotechnology could improve the economic independence of rural women.

In the case of sweetpotatoes in Kenya, because sweetpotato is an inferior commodity both in production and consumption, the main beneficiaries of the transgenic technologies will be the poor. Using modern biotechnologies for crops that are primarily grown by the poor excludes the risk of causing undesired equity effects. But a clear-cut separation between the crops of the poor and the rich is rarely possible. All types of farmers grow most of the common agricultural species. Potatoes in Mexico, for instance, are cultivated by small-scale as well as by large-scale producers. Interestingly, the productivity-increasing potential of the potato virus resistance technology is highest for the Mexican smallholders because, at present, they suffer the greatest virus-induced yield losses. Special care must be taken, though, to ensure that small farms have access to the new technology. This will require some initial policy support, in particular institutional adjustments in Mexico's potato seed markets. Carrying out a disaggregate analysis to explore distribution effects of new technologies is of particular importance whenever the target group is sufficiently heterogeneous.

If the great number of small-scale farmers in developing countries are included in biotechnological progress, it will not only reduce poverty and improve the food security situation of households but will also positively influence economic growth in a broader context through inter-sectoral spillovers. Such economy-wide technology effects and the dynamic benefits associated with biotechnology capacity-building in the respective countries have not been analyzed in the ex ante studies. It remains a challenge for future economic research to quantify these wider potential impacts of biotechnology in developing countries.

It must be stressed that the biotechnology projects scrutinized in Kenya and Mexico are specific cases that do not in every single respect allow for far-reaching generalizations. Realizing the welfare-increasing prospects of biotechnology in a broader scope will not be an easy task for developing countries. Some important questions are whether suitable biotechnologies for poor producers and consumers will evolve and who is going to develop them. Although the recombinant sweetpotato and potato technologies analyzed in this paper build on proprietary components, these components have been donated by the private sector, and the end-technologies are being developed by public research institutes. Thus farmers and food consumers capture the full benefits of the technology. No technology premium will be charged to recover research investments, and farmers can repeatedly reproduce the transgenic germplasm by themselves without violating any form of intellectual property protection. The benefit partition between technology suppliers and technology users would be different in a situation where private companies release new transgenic technologies on a commercial basis. In particular, the small-scale farmers' biotechnology access could remain limited if we relied solely on private activities in the future.

The biotechnology projects in Kenya and Mexico demonstrate the viability of public-private sector research partnerships for the benefit of developing countries. Such collaborative initiatives should be strengthened by appropriate policy incentives. Projects with a humanitarian touch can support the image of a private company. But of course there is reason to doubt that private sector technology donations will constitute the future model of North-South biotechnology transfer. This may be a promising niche option for genes and technology components that can be used in further public research on local semi-subsistence crops (such as sweetpotato), but it is unlikely that firms would give away technologies on a larger scale without charging apt royalty payments. Unquestionably, public investments into biotechnology will have to be expanded, both for public research and to cover licensing fees for proprietary technology elements.

Nonetheless, the private sector should be further encouraged to donate technologies to the South, especially when these transnational companies are struggling with a serious image problem. Every opportunity to deliver suitable biotechnologies to the poor should be exploited, as a straightforward recipe for how to better include developing countries in the biotechnology revolution is not available.

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REFERENCES

Alston, J.M., G.W. Norton, and P.G. Pardey (1995): *Science under Scarcity; Principles and Practice for Agricultural Research Evaluation and Priority Setting*. Cornell University Press, Ithaca, NY.

Biarnès, A., J.-P. Colin, and M. Santiago (eds.) (1995): *Agroeconomía de la Papa en México*. ORSTOM, Colegio de Postgraduados, Montecillo, Mexico.

von Braun, J., and E. Kennedy (eds.) (1994): *Agricultural Commercialization, Economic Development, and Nutrition*. The Johns Hopkins University Press, Baltimore.

Carey, E.E., S.T. Gichuki, P.J. Ndolo, G. Turyamureeba, R. Kapinga, N.B. Lutaladio, and J.M. Teri (1997): Collaborative Sweetpotato Breeding in Eastern, Central, and Southern Africa. In: *CIP Program Report 1995-96*. International Potato Center, Lima, pp. 49-57.

Cohen, J.I., C. Falconi, J. Komen, and M. Blakeney (1998): Proprietary Biotechnology Inputs and International Agricultural Research. ISNAR Briefing Paper, No. 39, International Service for National Agricultural Research, The Hague.

Davis, J.S., P. Oram, and J.G. Ryan (1987): *Assessment of Agricultural Research Priorities: An International Perspective.* Australian Centre for International Agricultural Research and International Food Policy Research Institute, Canberra and Washington, D.C.

Ghislain, M., M. Querci, M. Bonierbale, A. Golmirzaie, and R. Nelson (1997): *Biotechnology and the Potato; Applications for the Developing World.* International Potato Center, Lima.

Hayami, Y., and R.W. Herdt (1977): Market Price Effects of Technological Change on Income Distribution in Semisubsistence Agriculture. *American Journal of Agricultural Economics* 59 (2), pp. 245-56.

James, C. (1999): Global Review of Commercialized Transgenic Crops: 1999. ISAAA Briefs, No. 12, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

Jansson, R.K., and K.V. Raman (eds.) (1991): *Sweet Potato Pest Management: A Global Perspective.* Westview Press, Boulder.

de Janvry, A., G. Graff, E. Sadoulet, and D. Zilberman (1999): Agricultural Biotechnology and Poverty: Can the Potential be made Reality? Paper presented at the conference “The Shape of the Coming Agricultural Biotechnology Transformation”, 17-19 June, Tor Vergata University, Rome.

ODI (1999): The Debate on Genetically Modified Organisms: Relevance for the South. Briefing Paper 1, Overseas Development Institute, London.

Omosa, M. (1997): *Current and Potential Demand for Fresh and Processed Sweetpotato Products in Nairobi and Kisumu, Kenya.* International Potato Center, Lima.

Qaim, M. (1999a): The Economic Effects of Genetically Modified Orphan Commodities: Projections for Sweetpotato in Kenya. ISAAA Briefs, No. 13, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

Qaim, M. (1999b): Potential Benefits of Agricultural Biotechnology: An Example from the Mexican Potato Sector. *Review of Agricultural Economics* 21 (2), pp. 390-408.

Qaim, M., and J. von Braun (1998): Crop Biotechnology in Developing Countries: A Conceptual Framework for Ex Ante Economic Analyses. ZEF Discussion Papers on Development Policy, No. 3, Center for Development Research, Bonn.

RAFI (1999): Traitor Technology; The Terminator's Wider Implications. RAFI Communiqué (January/February), Rural Advancement Foundation International, Winnipeg.

Rivera-Bustamante, R. (1995): An Example of Transfer of Proprietary Technology from the Private Sector to a Developing Country. In: D.W. Altman, and K.N. Watanabe (eds.). *Plant Biotechnology Transfer to Developing Countries*. R.G. Landes Company, Austin.

Wambugu, F.M. (1996): Control of African Sweet Potato Virus Diseases through Biotechnology and Technology Transfer. In: J. Komen, J.I. Cohen, and Z. Ofir (eds.). *Turning Priorities into Feasible Programs*. Intermediary Biotechnology Service, The Hague, pp. 75-81.

Zhao, X., J.D. Mullen, and G.R. Griffith (1997): Functional Forms, Exogenous Shifts, and Economic Surplus Changes. *American Journal of Agricultural Economics* 79 (4), pp. 1243-51.

Chapter 10

INSTITUTIONAL ISSUES IN BIOTECHNOLOGY APPLICATIONS: CONCEPTS AND EMPIRICAL EVIDENCE FROM KENYA

Margaret Karembu and Michael Njuguna

Abstract: This paper discusses various institutional issues that should be considered to successfully apply agricultural biotechnology to smallholder agriculture. Participatory approaches – from the first phase of problem definition to the final phase of technology adoption – are prerequisites for optimizing biotechnology's benefits for the poor. A case study dealing with tissue culture bananas in Kenya is discussed in greater detail. It exemplifies the value of effective partnerships between various public and private sector institutions, including community-based groups, that build on comparative advantages. Banana growers were involved at an early stage of project conceptualization to better understand their needs and constraints. In this way, they developed "ownership" of the technology early on and did not feel that the technology was being imposed on them. Preliminary evaluations show that resource-poor farmers could reap the largest benefits of tissue culture bananas.

1 INTRODUCTION

Whether biotechnological innovations can offer relevant solutions to the problems of small-scale farmers in developing countries has been a subject of debate for quite a while. Of particular concern during the last decade has been the search for the models and specific conditions needed to optimize these technologies' benefits for the poor.

Two predominant approaches have been used extensively: technology-push and interactive bottom-up procedures. In the former, scientists identify research targets based on their assessments of the highest theoretical yields weighed up against research costs for a given innovation. This model assumes that innovations deemed advantageous from a research and development (R&D)

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point of view will successfully find their way to the marketplace. In other words, supply will create demand. The interactive bottom-up approach, on the other hand, emphasizes market needs. Through socioeconomic and diffusion research it investigates the conditions under which prospective users may or may not adopt the technology. According to this model, the needs of the end-user of the technology and subsequent follow-ups are the most important aspects of successful innovation development.

Regardless of the model, empirical evidence from countries that have embraced agricultural biotechnology indicates that the key to successfully providing resource-poor farmers with biotechnology is the development of an institutional and policy framework that takes into account the complexities and needs of small-scale agriculture. This paper describes the types of institutional issues and challenges associated with applying biotechnology as experienced by an ongoing project in Kenya to benefit small-scale banana producers. The project clearly demonstrates that biotechnology can be commercialized within small-scale agriculture, which is the predominant farming system in developing countries, and that there is a real chance to advance the economy through such efforts. The challenge lies in building selective partnerships that bring institutions with comparative advantages together so that they can respond to different needs and issues as they arise. If facilitation and monitoring mechanisms are put in place from the first phase of project conceptualization to the final phase of technology adoption, the focus and success of the project will be maintained.

The paper is divided into four sections, including this introduction. Section 2 focuses upon the banana biotechnology study in Kenya, providing a brief account of how the need for the technology was conceptualized. The section also describes the different functions of the organizations involved in transferring the technology to small-scale farmers. In particular, the role played by the International Service for the Acquisition of Agri-biotech Applications (ISAAA) in maintaining the project's focus and in keeping the various institutions involved together is highlighted. Judging from the synergism that collaboration with the different organizations created, it is clear that agricultural technology transfer can only be successfully achieved through concerted efforts that include all the relevant stakeholders in the agricultural sector and beyond. Section 3 synthesizes the lessons learned and discusses some institutional issues that we consider crucial for biotechnology transfer and application in developing countries. We identify the development of a mechanism for acquiring technologies from the private sector and the establishment of an appropriate technology delivery system with links to credit providers as institutional pre-requisites for optimizing biotechnological benefits for the poor. Section 4 summarizes the main findings and draws some conclusions.

2 THE BANANA PROJECT CASE STUDY

Banana is an important staple food in many parts of Africa and also a source of income to many small-scale farmers. According to the Kenyan Ministry of Agriculture (MOA, 1994), banana production has been gaining in popularity due to its high price and available markets created by the overall poor performance of major cash crops, such as coffee and tea, in the international market. Unfortunately, the realized yields in Kenyan banana production still fall far below their potential due to the use of unclean planting materials. Lack of clean planting material has resulted in farmers planting sword suckers obtained from their own old plantations or from other farmers. Over the years, this has led to a synergistic increase in the spread of diseases and pests, which ultimately contributes to the low average yield of less than 10 tons per hectare. Environmental degradation, low levels of farm inputs, and poor farming practices have further aggravated this problem. These factors, coupled with the fact that banana has only recently been a priority crop in Kenyan agricultural research, created a fruit shortage in the local market.

Responding to the identified need of making improved and clean planting materials accessible to resource-poor, small-scale banana growers, a tissue culture banana project was started in 1996 by ISAAA and the Kenya Agriculture Research Institute (KARI). Through ISAAA's facilitation, several public and private sector organizations have collaborated with KARI to transfer the technology to small-scale farmers.

2.1 Project Objectives

The specific objectives of the banana tissue culture project were:

- to establish field trials for demonstrating the relative advantages of tissue culture plants over traditional suckers;
- to transfer the technology to small-scale farmers;
- to expand the genetic base of banana and the varietal choice for growers by exchanging and introducing selected superior banana varieties with enhanced pest and disease resistance and higher yield potentials from reputable breeding programs in the world;
- to strengthen the capacity (institutional and human) for the transfer and application of biotechnology in banana production by establishing links with partners (public and private) for efficient multiplication, hardening, testing and distribution of planting materials; and

- to explore and encourage business opportunities derived from tissue culture bananas by promoting collaboration between researchers, farmer groups, commercial enterprises and government ministries in the commercialization of biotechnology products.

2.2 Institutions and Technology Transfer Model

The project started with a need that had been identified and documented during a survey conducted in 1993. As the lead institution, ISAAA had to have a clear vision of the project's direction. The first task was to identify a suitable collaborator to implement the project, and KARI was identified as best placed to do so. It had the comparative advantage of possessing a network of research centers throughout the country – including in banana-growing areas. In addition, KARI had the human resource capacity to conduct on-station cultivar evaluations and agronomic studies for varieties that were not locally grown. Most importantly, the institute had the necessary infrastructure in terms of motor vehicles and trained personnel to offer preliminary extension services to farmers.

Initially, four banana-growing areas were identified: Thika in the Central province, Kisii in Nyanza, Embu in the Eastern, and Mtwapa in the Coast province. The respective KARI regional centers would undertake the project. To enhance the possibility of success, only the Thika and Kisii areas would take part in the first year of the project; Embu and Mtwapa would then follow in subsequent years. This approach allowed the two centers taking part in the first year of the project to receive the necessary support and to overcome the inevitable "teething troubles".

It was also necessary to identify a collaborator who could supply the initial planting materials for both the KARI stations and the on-farm field trials. Since no source in Kenya could supply the quantities that were required, ISAAA identified a private company in South Africa with a long experience in tissue culture multiplication: DuRoi Laboratories. This was important because the project needed to use high quality materials to make a difference. A local counterpart in Kenya was also needed to handle the materials after they arrived from South Africa, and so the private company Genetic Technologies Limited (GTL) was brought on board because of its experience with tissue culture work in other crops.

In this model, on-station trials were carried out concurrently with the on-farm trials. This was possible because most of the cultivars that were used had been previously evaluated in South Africa, where farmers had been growing them for many years. Participatory Rural Appraisals (PRAs) were conducted to identify Kenyan farmers for these initial on-farm trials. They were selected in part based on their willingness to provide a certain degree of project commitment, (i.e., supply labor and farmyard manure). Access to water was also a critical factor because tissue culture banana plantlets are very sensitive to water stress. To ensure a maximum audience, farmers near community establishments, such as local markets, religious centers, dispensaries etc., were preferred for on-farm demonstrations.

Technical backstopping was also considered crucial for the project's success. The Institute of Tropical and Subtropical Crops (ITSC), a public institution in South Africa, was identified as possessing the relevant experience and human resource capacity to perform this task. Since the beginning of the trials, experts from ITSC have been making three visits every year to assess performance and offer needed advice on field management.

KARI collected data from both on-farm and on-station trials and was involved in managing and supervising all the activities in these trials. ISAAA has closely monitored all the project activities. The African Technology Policy Studies (ATPS) network funded research carried out by Kenyatta University to investigate the optimal conditions under which banana biotechnology would diffuse to resource-poor farmers (Karembu, 1999). This was important since past experiences with new innovations have generally shown that if the needs and interests of end-users are overlooked, then there will be little if any adoption of the technology.

In addition, in 1998 ISAAA encouraged an independent institution, the Center for Development Research (ZEF) in Germany, to undertake an ex ante impact assessment study on the tissue culture banana project in Kenya. Significantly, the study has shown that small-scale farmers could reap more benefits from the introduction of tissue culture bananas than large-scale farmers (Qaim, 1999).

The performance of the demonstration trials both in the station and in the farmers' fields has been outstanding. On average, small-scale farmers have been harvesting tissue culture bananas with a bunch weight of more than 40 kg – compared to 20-30 kg from traditional suckers. These demonstration trials have also created enormous interest among small-scale farmers in the project areas. As a result, the demand for tissue culture planting materials has increased dramatically. To facilitate the acquisition of these materials by small-scale farmers, KARI and ISAAA have collaborated to identify a church group and several community-based groups in different areas to establish banana nurseries as local distribution points. Farmers in the four project areas can now access clean tissue culture planting materials through these nurseries. The purpose of this part of the project was to help establish the nurseries and to create the link to the tissue culture sources. This strategy will ensure the sustainability of the project after the funding period comes to an end. The Rockefeller Foundation and the International Development Research Center (IDRC) have generously funded this phase of the project.

2.3 Project Achievements

New cultivars have been introduced. Local banana varieties have been evaluated, and new varieties introduced. So far there are five new cultivars with very good performance: Goldfinger, Grand Nain, Chinese Cavendish, Giant Cavendish, and Valery. These cultivars will now be targeted for commercialization. Two of the cultivars, Dwarf Cavendish and Goldfinger, were found to be unsuitable in some areas. Dwarf Cavendish developed a fungal fruit disease (cigar end rot) in Central province but performed excellently in the Coast region. Preliminary market studies indicated that Goldfinger, which had been promoted as a dessert variety, was less appealing to consumers because of its short shelf life and weak finger-holding capacity. The variety is, however, doing well as a cooking banana.

Establishment of distribution system. A distribution system for banana tissue culture material has been developed and several distribution agents were brought on board. These include community-based organizations (CBOs), individual entrepreneurs, and church organizations.

Link with credit providers. A socioeconomic survey conducted in the rural banana-growing areas in Kenya revealed a high demand for credit (Qaim, 1999). Efforts have been made to link the small-scale farmers with credit providers who will provide this much-needed credit at commercial interest rates.

Quality control. To ensure that no sub-standard planting materials are circulated in the country, a Banana Growers Association (BGA) is being formed that will work closely with established quality control mechanisms within the country, such as the Kenyan Plant Health Inspection Service (KEPHIS). BGA will also be responsible for pricing control measures with respect to tissue culture plantlets and the resulting fruits.

Banana marketing. Owing to the highly informal and undefined markets for bananas, a high priority has been given to establishing organized markets like those that exist for other agricultural commodities such as coffee, tea or milk. Banana growers are now organizing themselves into cooperatives and farmers' associations to ensure proper marketing of their crop and to minimize exploitation by middlemen. This organization will also improve the ability of small-scale farmers to access credit through their marketing association.

Table 1: Summary of the project's main activities and organizations involved

Organization	Private/public	Activities/responsibilities
KARI	Public	Project implementation
Kenyatta University	Public	Technology diffusion research to provide data on downstream issues
ISAAA	Non-profit	Facilitation and monitoring
ITSC	Public	Technology backstopping
CBO	Non-profit	Provision of credit facilities and distribution system
Farmer groups	Civil society	Establishment of tissue culture nurseries, quality control and marketing system
DuRoi/GTL	Private	Private sector link for provision of planting material
ZEF	Public	Ex ante technology evaluation

Training. The overall project goals were achieved in part due to investments in training farmer groups and scientists. Training in nursery management, sourcing of initiation materials, field management practices, disease diagnostics and post harvest handling equipped the relevant groups with useful skills and the knowledge needed to ensure sustainability in technology transfer.

2.4 The Role of ISAAA

ISAAA supports the implementation of the banana project and other biotechnology initiatives through a series of activities. As a facilitator in all these projects, ISAAA's role entails:

- bringing different institutions together into synergistic partnerships;
- helping to maintain a working relationship between the different institutions while maintaining project focus; this is important because different institutions have different interests that can easily divert them from their project commitment;
- facilitating the establishment of biosafety and foodsafety regulatory development;
- encouraging independent technology impact assessments; and
- addressing national needs in building capacity in intellectual property rights (IPRs), primarily licensing and contracts; these needs are being met through an internet-based virtual workshop.

3 GENERALIZED INSTITUTIONAL ISSUES

Careful analysis of the banana case study reveals that the transfer of biotechnology in smallholder agriculture is feasible but requires putting in place institutional mechanisms that provide skills, knowledge and financial resources for the benefit of the poor. Successful biotechnology application depends upon how well such institutional issues are handled by the relevant institutions. These should operate in synergy at all stages, from initial technology acquisition, through its placement in farmers' fields, to the marketing of the agricultural commodity. We shall now discuss these issues based on experiences gained and lessons learnt from the case study described above.

3.1 Is there a Need for the Technology?

Given the fast rate at which the biotechnological revolution is spreading, and given its proven and potential contribution to resolving such major problems as rapid population growth, plant and animal diseases, and environmental degradation in both industrial and developing countries, questioning the need for biotechnology is actually irrelevant. Biotechnology has already demonstrated its impact. The observed imbalance, however, between technology development and its application in resolving the specific problems of target communities is important. In the case of agricultural technologies, for instance, farmers are very often given "solutions" that ignore their views, needs and aspirations. Indeed, there is often an implicit belief that farmers are ignorant, conservative, superstitious and irrational when it comes to new technologies. But ignoring the richness and diversity of these farmers' diverse indigenous knowledge systems, which have been passed on through generations, often results in applying the wrong strategy (technology) to a problem. In this context, the question of the need for biotechnology becomes quite relevant.

There are various options for resolving farmers' problems, and these should be considered together with the new technology. In this way, farmers can develop ownership of the technology early on and will not feel that the technology is being imposed on them. Likewise, it is important to set up an institutionalized mechanism in which farmers participate to assess needs and set priorities. This mechanism should consist of a multidisciplinary decision-making team of stakeholders, including government, research institutions, CBOs, farmer groups and industry and development partners. A narrow sectoral approach to priority setting will stifle biotechnology transfer since the whole placement process is interrelated and interdependent. Suitable intervention measures might also be needed beyond the agricultural sector.

Once the need for a new technology is recognized, a comprehensive national strategy must be developed to match this need to appropriate, available technologies. The private sector, which has taken the lead in biotechnology development, may not see sufficient marketing potentials in developing countries, and so might underinvest in projects related to small-scale agriculture. The next question then becomes that of justifying a certain technology in terms of its relevance to farmers (i.e., assessing its practical relevance).

3.2 Appropriateness of a Particular Technology

Quite often, technologies are "thrown" to farmers without due consideration of their relevance within the context of the underlying problem. Whatever the technology, however, farmers deciding whether to use it implicitly rely on certain criteria. Research literature has widely documented some of these criteria, which include the following (Rogers, 1983; Rothwell and Zegveld, 1983; Odour, 1993; Bwisa and Gachuhi, 1999):

- perceived compatibility of the technology within existing socio-cultural structures;
- the relative advantage of the innovation over existing technologies and/or alternatives;
- the skill requirement for using the technology;
- the ease of experimentation (i.e., testability which is related to divisibility); and
- the extent to which the innovation improves productivity (i.e., the immediate returns measured against the time taken for any observable or visible gains from the use of the technology to appear).

In the area of biotechnology, there are additional criteria that should be considered from a national point of view, such as IPR management and biosafety issues. There must be clear guidance about these issues to successfully develop a biotechnology product. The usefulness of collaborating with organizations from other countries, which often have more experience in technology adaptation and related regulatory procedures, cannot be overstated. There are also fears and concerns about the extent to which farmers' indigenous knowledge systems will be compromised by biotechnology applications. The expertise from several specialized non-governmental organizations (NGOs) should be used to educate and advise farmers about any concerns that they might have in regards to indigenous knowledge systems when deciding on which technology to adopt.

Product marketing issues must also be addressed. Commercial markets for biotechnology products, just like other agricultural commodities in developing countries, are often unstable, and this situation has been exacerbated by market liberalization efforts associated with structural adjustment programs. Farmers may be pessimistic about adopting some technologies – especially if market forces place limitations and restrictions on biotechnology products. In the case of a cash crop like coffee, for example, there are fears that the European market might refuse to accept transgenic varieties. All these issues need to be resolved, in part by bringing institutions with competence in such areas on board so that a technology choice can be clearly justified. Only at that point would delivery mechanisms become relevant.

3.3 Technology Delivery Systems

Since most proprietary technologies are held by the private sector, an honest broker is needed to negotiate for the technology and form a private-public sector partnership. Because they are fairly well equipped to handle adaptation research once the technology is acquired, national agricultural research institutes are important public partners. Having identified the technology provider and justified the technology choice, the next concern is to deliver a product to farmers. Farmers should gain experience with the technology before its release. This can be achieved through on-station and on-farm evaluation and demonstration trials. Potential distribution bottlenecks should also be addressed at this stage.

A distribution mechanism needs to be put in place to ensure that the product is routinely and easily accessible. Institutions with comparative advantage should be identified and local partnerships developed. These may be either public (e.g., ministries of agriculture, research and extension institutions) or private (e.g., commercial firms, CBOs, and NGOs). The capacity of the infrastructure and of other support institutions and networks also needs to be considered before appropriate players for the acquisition, testing and adaptation of the technology to local conditions can be identified. Expertise in technical backstopping and micro-credit schemes should especially be obtained. Overall, effective technology delivery requires the adoption of the most economically viable options for farmers, which, in general, are those that require the fewest additional requirements from them. As Bunders (1990) explains, success will depend on the following:

- the availability of reliable scientific knowledge about the farming systems;

- the existence of national/regional organizations to facilitate the adaptation and diffusion of biotechnological innovations;
- the existence of a local scientific infrastructure for biotechnology development; and
- meeting input and factor requirements, including access to credit, education and extension, land, technological equipment, and labor among others.

Very limited access to internal and external inputs – as well as the cultural beliefs regarding certain inputs – may hinder diffusion. For example, studies in connection with the banana biotechnology case study found that in some cases farmers were unwilling to use synthetic fertilizers because they believed that this negatively affects the quality of bananas during ripening (Karembu, 1999).

3.4 Adaptive Responses to Possible Weaknesses

A feedback mechanism is essential. Data from diffusion research provide valuable insights about emerging issues and shortcomings in the technology adoption process. Such issues will likely include farmers' perceptions of the technology, management practices and necessary adjustments, skill requirements, diversification, gender issues and other social and ethical questions. Furthermore, widespread technology adoption could require the establishment of new links between farmers and credit providers. Sometimes, especially in smallholder agriculture, this might require farmers to organize themselves into credit-worth units so that peer pressure can substitute for traditional forms of collateral. Socioeconomic research can also assess the existence or non-existence of commercial markets for the commodities and provide new information about the marketing infrastructure. Post-harvest handling, storage and transport and other marketing issues will require thorough investigation as the adoption level rises. Potential outlets should be identified and a marketing information system developed early on so that farmers can be informed in a timely manner about seasonal demand/supply patterns and associated pricing regimes. Quality control issues also need to be addressed as commercialization plans are drawn up. Finally, a flexible project design is needed so that the initial strategy can be adapted to possible weaknesses in the institutional setting.

3.5 Ensuring Sustainability

Ensuring sustainability of the whole biotechnology project requires lead organizations to perform certain roles. These include honest brokerage, coordination, the establishment of funding mechanisms, facilitation, monitoring, the identification and inclusion of new partners as needs arise, negotiating with credit providers, disseminating information and carrying out impact assessments.

4 CONCLUSION

We recommend some general principles for effective institutional partnerships and collaborations that – if taken into account early in a project's design – would surely optimize the benefits of biotechnology applications for the poor.

- Any approach should be participatory. Only when the needs and perceptions of the target group (i.e., poor agricultural producers and consumers) are explicitly taken into account in project planning, implementation and evaluation can biotechnology contribute to poverty alleviation and to a wider economic advancement in developing countries.
- The approach should be integrative. The use of biotechnology applications requires that the activities of all stakeholders be integrated into other economic policies. A case in point is biotechnology risk assessment, for which, as Mugabe (1999) asserts, it may not be necessary to establish new structures but rather to integrate risk assessment and management issues into existing environmental, social, political, health and agricultural regimes.
- It should be built on collective action. The efforts of one institution cannot achieve the same effects as collective responsibility. The promotion of biotechnology requires "coalitions" at local, national, regional and international levels (Brenner, 1999). This also includes the establishment of an innovative monitoring mechanism that identifies weaknesses, strengths, and possible adaptive responses at all stages (invention, innovation, and diffusion). Such a mechanism would act like a "biotechnology watchdog" and should therefore be composed of persons of professional repute, that includes all relevant stakeholders, (i.e., farmers, consumers, scientists, industrialists etc.).
- Information and communication systems must be improved. Many studies have shown that optimism about biotechnology increases with factual knowledge. Better communication systems are therefore very crucial. Even at the consumer level, there is need for factual information so that responsible and judicious decisions can be made about

biotechnology acceptance. A response to these information needs has already been proposed for Africa in the form of the African Biotechnology Stakeholders Forum (ABSF). ABSF's mission is to create an enabling environment by demonstrating where Africa can participate and benefit from biotechnology, including the benefits of an enhanced understanding and awareness of aspects related to biotechnology, including biosafety and IPRs. Information exchange should be based on trust, and it must be acknowledged that biotechnological issues cut across public and private sector areas and that all the stakeholders' activities are interconnected and interrelated.

Finally, an international compilation of available biotechnologies and on-going activities in both developed and developing countries would provide very useful information that could be used by developing countries to formulate policies about future biotechnology efforts.

REFERENCES

Brenner, C. (1999): Agricultural Biotechnology R&D in Africa: Structural Constraints. Paper presented at the regional workshop on "Biotechnology Assessment–Regimes and Experiences", organized by the African Center for Technology Studies (ACTS), 27-29 September, Nairobi.

Bunders F.G.J. (ed.) (1990): *Biotechnology for Small-Scale Farmers in Developing Countries: Analysis and Assessment Procedures*. VU University Press, Amsterdam.

Bwisa, H.M, and A.R. Gachuhi (1999): An Investigation into Factors that Influence the Diffusion and Adoption of Inventions and Innovations from Research Institutes and Universities in Kenya. ATPS Working Paper, No. 18. African Technology Policy Studies Network, Nairobi.

Karembu, M.G. (1999): Small Scale Farmers Adoptive Responses to Banana Biotechnology in Kenya: Implications for Policy. Mimeo., ATPS Research Progress Report, African Technology Policy Studies Network, Nairobi.

MOA (1994): *Annual Report*. Ministry of Agriculture, Nairobi.

Mugabe, J. (1999): Biotechnology or its Risks: Africa's Misinformed Dilemma. Paper presented at the regional workshop on "Biotechnology Assessment–Regimes and Experiences", organized by the African Center for Technology Studies (ACTS), 27-29 September, Nairobi.

Odour, W. (1993): Adaptive Responses to Modern Agricultural Technology: A Case Study of Kitui Farmers in the Semi-Arid Regions of Eastern Kenya. Mimeo., ATPS Working Paper, African Technology Policy Studies Network, Nairobi.

Qaim, M. (1999): Assessing the Impact of Banana Biotechnology in Kenya, ISAAA Briefs, No. 10, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

Rogers, E. (1983): *Diffusion of Innovations*. Third edition, The Free Press, London.

Rothwell, R., and W. Zegveld (1983): *Industrial Innovations and Public Policy: Preparing for the 1980s and the 1990s*. Frances Pinter, London.

Chapter 11

THE ROLE OF BIOTECHNOLOGY FOR FOOD CONSUMERS IN DEVELOPING COUNTRIES

Howarth E. Bouis

Abstract: This paper assesses the potential benefits that biotechnology can provide food consumers in developing countries by examining the recent history of attempts to improve the micronutrient content of food crops, efforts that have used both biotechnology and traditional plant breeding. In developing countries, micronutrient deficiencies affect many of the poor, whose diets consist mostly of staple foods. Breeding to enhance the micronutrient levels in staple foods could help reduce this problem. Since trace minerals are also important for plant nutrition, related breeding may increase farm productivity at the same time. Plant breeding is more efficient than alternative interventions already in place for reducing micronutrient malnutrition. Identifying the appropriate combination of traditional and biotechnology tools should be based on cost-effectiveness considerations. The potentially enormous benefits to the poor in developing countries in relation to costs are so high that research in this area should be vigorously pursued.

1 INTRODUCTION

In order to assess the potential benefit of biotechnology for food consumers in developing countries, this paper examines the recent history of attempts to improve the micronutrient content of staple foods, efforts that have used both biotechnology and traditional plant breeding. This concrete example will serve to illustrate several key generic issues associated with using biotechnology to breed for characteristics that benefit consumers. Biotechnology can, of course, be used to help solve a number of problems, but its potential usefulness depends on the context of a particular problem. It will be necessary, therefore, to discuss in some detail the context of breeding for improved micronutrient density.

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Taken together, mineral and vitamin deficiencies affect a greater number of people in developing countries than protein-energy malnutrition. Because trace minerals are important not only for human nutrition but also for plant nutrition, plant breeding has great promise for making a significant, low-cost, sustainable contribution to reducing micronutrient deficiencies, particularly mineral deficiencies. It may also have important spin-off effects for environmentally beneficial increases in farm productivity for developing countries (Cary et al., 1994; Welch et al., 1993; Kannenberg and Falk, 1995; Graham and Welch, 1996; Graham et al., 1999).

The following section briefly summarizes the extent and consequences of micronutrient malnutrition in developing countries, as well as the effectiveness of the non-agricultural interventions currently being used to address this problem. We then argue that plant breeding is a low-cost, sustainable intervention that can substantially reduce micronutrient malnutrition. This is a new, perhaps not yet widely accepted strategy for addressing this enormous problem, whether using biotechnology or conventional breeding techniques. The progress of such a strategy using conventional breeding techniques is then reported, focusing on rice. Recent advances using biotechnology to improve the micronutrient content of rice are also presented, which permits a discussion of the ways in which conventional and biotechnology approaches are complementary and of what biotechnology can accomplish that conventional breeding cannot. Finally, we draw some general lessons for assessing the potential of biotechnology to improve human nutrition.

2 MICRONUTRIENT MALNUTRITION: EXTENT, COSTS, ALTERNATIVE INTERVENTIONS

Only relatively recently have nutritionists working in developing countries been able to demonstrate that many children and adults, particularly women in their childbearing years, suffer more from a lack of essential vitamins and minerals in their diets than from a lack of calories — even during relative economic and political stability. People are unaware that their diets lack these trace nutrients, and they do not associate these deficiencies with listlessness, poor eyesight, impaired cognitive development and physical growth, and more severe bouts of illness (sometimes leading to death). Accordingly, this general problem of poor dietary quality has been dubbed "hidden hunger".

In an observational study, researchers from Johns Hopkins University working in Indonesia showed a correlation between progressively serious eye damage in children and increased child mortality rates. This empirical information was consistent with a long suspected link between vitamin A deficiency and the high child mortality rates common in developing countries. To test this hypothesis more rigorously, 10,000 Indonesian children were given high-dose vitamin A capsules (VAC) and 10,000 children were given a placebo (a low percentage of these children, no more than one percent, had clinically visible eye damage). Mortality rates were found to be 34 percent lower for children who received VAC.

Such a large reduction in mortality was so startling and unexpected that eventually it was necessary to conduct seven similar experiments in Africa and Asia (with similar results on average) before it was widely accepted by the international nutrition community (in the late 1980s) that widespread distribution of VAC could significantly reduce child mortality and should be made a high priority for government intervention. These dramatic, new research findings in the area of vitamin A deficiency also helped to focus more attention and spur further research related to other micronutrient deficiencies, in particular iron and iodine deficiencies.

The World Health Organization (WHO) now compiles statistics on a regular basis about the extent of micronutrient deficiencies and this has revealed the enormous magnitude of the problem. WHO reported in 1994 that 3 million pre-school age children had eye damage due to a vitamin A deficiency and another 200 million are sub-clinically affected at a severe or moderate level. Annually, an estimated 250,000-500,000 pre-school children go blind from this deficiency, and about two-thirds of these children die within months of going blind. Globally, over three billion people are iron-deficient (ACC/SCN, 2000). The problem for women and children is more severe because of their greater physiological need for iron. In developing countries, more than 40 percent of non-pregnant women and pre-school children and more than one-half of pregnant women have anemia. Of the approximately 500,000 maternal deaths that occur each year due to childbirth, mostly in developing countries, anemia is the major contributor or sole cause in 20-40 percent of such deaths. Iron deficiencies during childhood and adolescence impair physical growth, mental development and learning capacity. In adults, iron deficiency reduces the capacity to do physical labor. Deficiencies in several other micronutrients, zinc in particular, may be similarly widespread with equally serious consequences for health (Gibson, 1994). However, because there are no specific indicators to screen for zinc deficiencies (other than a positive health response to supplementation), zinc has not received as much attention.

The costs involved in fortification and supplementation are considerable. The recurrent, annual, lower-bound estimate for iron supplementation is US $2.65 per person when administrative costs are taken into account (Levin et al., 1993). A lower-bound estimate for iron fortification is 10 cents per person per year. In a populous country such as India (total population 1 billion) there may be as many as 28 million anemic pregnant women in any given year. Treating only half of those women through a well-targeted supplementation program could cost as much as US $37 million per year. Iron fortification for half the entire population could cost $44 million per year. Notwithstanding these cost estimates, the benefits of properly managed interventions can be quite significant. The World Bank's World Development Report 1993 found that micronutrient programs were among the most cost-effective of all health interventions. A World Bank document (1994) estimates that deficiencies of just vitamin A, iodine, and iron alone could waste as much as 5 percent of gross domestic product (GDP) in developing countries, but addressing them comprehensively and sustainably would cost less than one-third of a percent of GDP. Nevertheless, it is difficult for governments and international agencies to mobilize resources of this magnitude.

Although successful supplementation and fortification do not require a substantial change in individual behavior, these interventions only treat the symptoms and not the underlying causes of micronutrient deficiencies. This has led many to advocate the use of "food-based" interventions, such as nutrition education and the promotion of home vegetable gardens, that address the underlying cause of poor quality diets and also provide a range of other important nutrients. This approach, however, means changing human behavior, which can be both expensive and difficult.

New and compelling scientific evidence is rapidly accumulating to support the claim that nutrition and health in developing countries can be dramatically improved by reducing micronutrient malnutrition. It is an enormous opportunity. Nevertheless, there is some frustration at the lack of appropriate, well-developed tools for developing countries to solve the problem of micronutrient deficiencies quickly and at a reasonable cost.

3 CAN A PLANT BREEDING STRATEGY WORK? FIVE KEY QUESTIONS

A strategy of breeding plants that enrich themselves and load high amounts of minerals and vitamins into their edible parts has the potential to substantially reduce the recurrent costs associated with fortification and supplementation. But this will be successful only if farmers are willing to adopt such varieties, if the edible parts of these varieties are palatable and acceptable to consumers, and if the incorporated micronutrients can be absorbed by the human body. Indeed, five core questions must be addressed to examine the feasibility of such a plant breeding strategy.

3.1 Is it Scientifically Feasible to Breed Micronutrient-Dense Staple Food Varieties?

At least three agricultural research projects in developed countries have successfully manipulated the mineral uptake of plants and the mineral content of plant seeds, and all these projects have been commercially successful. Zinc-dense wheat varieties, developed at the Waite Agricultural Research Institute of the University of Adelaide, are already being grown on a commercial basis in Australia (Rengel and Graham, 1995). In the United States, an iron-efficient soybean has been developed to overcome problems of iron "deficient" soils, and cadmium levels in durum wheats have been reduced through plant breeding to meet quality standards in countries importing US wheat.

3.2 What are the Effects on Plant Yields? Will Farmers Adopt Such Varieties?

Results from research at Waite and elsewhere has shown that where the soil is deficient in a particular micronutrient, seeds containing more of that nutrient have better germination, better seedling vigor and/or more resistance to infection during the vulnerable seedling stage (Pearson and Rengel, 1995; McCay et al., 1995). Since these crop establishment benefits can result in higher crop yield, the specific breeding goals for human and plant nutrition largely coincide.

A soil is said to be "deficient" in a nutrient when the addition of a fertilizer containing that nutrient produces better growth. But the amount of the mineral micronutrient that is added to the soil to improve growth is usually small compared to the total amount of that mineral found in the soil. Because the trace mineral is chemically bound to other elements in the soil, the major part of the trace mineral is "unavailable" to plants. An alternative view, therefore, is that instead of soil deficiency there is a genetic deficiency in the plant. Tolerance to micronutrient-deficient soils, termed *micronutrient efficiency*, is a genetic trait of a genotype or phenotype that causes a plant to be better adapted or to produce higher yields in a micronutrient-deficient soil than the average cultivar of the species (Graham and Rovira, 1984). Growing zinc-efficient plants on zinc-deficient soils, for example, "tailors the plant to fit the soil" instead of "tailoring the soil to fit the plant" (Foy, 1983). These efficient genotypes exude substances from their roots that chemically unbind trace minerals from other binding elements and make trace minerals available to the plant.

It is well understood that without replacement the depletion of soil nitrogen takes only a few years. Consequently, it is pointless to breed for greater tolerance to nitrogen-deficient soils. Phosphorus efficiency results in overall improvements in cost-efficiency but, without replenishment, depletion of soil phosphorous will also eventually occur. In contrast, the depletion of mineral micronutrients may take hundreds or thousands of years – or may likely never occur at all – due to various inadvertent additions and other processes, such as minerals carried in windblown dust (Graham, 1991). Based on a number of soil surveys, particularly in China where the most extensive surveys have been done, it is estimated that at least 50 percent of the arable land used for crop production worldwide is low in one or more of the essential micronutrients. For example, although iron is the fifth most abundant element in the earth's crust, the fraction of soil iron that is in soluble form for absorption by plants may only be 10^{-13} of total soil iron. Depletion of soil iron is never an issue; instead, the issue is the ability of the plant to mobilize sufficient iron to satisfy its needs (Han et al., 1994). Zinc deficiency is probably the most widespread micronutrient deficiency in cereals. Sillanpaa (1990) found that 49 percent of a global sample of 190 soils in 25 countries were low in zinc. Unlike other micronutrients, zinc deficiency is a common feature of both cold and warm climates, in soils drained and flooded, acid and alkaline, heavy and light (Rahman et al., 1993).

Good nutrition balance is as important for disease resistance in plants as it is in humans. The efficient uptake of mineral micronutrients from the soil is associated with disease resistance in plants, which leads to decreased use of fungicides. Micronutrient deficiency in plants greatly increases their susceptibility to diseases, especially fungal root diseases of the major food crops. The picture emerging from four decades of physiological studies of roots is that phosphorus, zinc, boron, calcium and manganese are all required in the external environment of the root for membrane function and cell integrity. In particular, phosphorus and zinc deficiencies in the external environment promote the leaking of cell contents such as sugars, amides and amino acids. These substances are chematoxic stimuli to pathogenic organisms. It also appears that micronutrient deficiency predisposes the plant to infection, rather than the infection causing the deficiency through its effect on root pruning (Sparrow and Graham, 1988; Thongbai et al., 1993). Breeding for micronutrient efficiency can also confer resistance to root diseases that had previously not been amenable to breeding solutions. This could mean a lower dependence on fungicides.

Micronutrient-efficient varieties grow deeper roots in mineral deficient soils and are better at tapping subsoil water and minerals (Grubb, 1994; Brown et al., 1994). When topsoil dries, roots in the dry soil zone (which are the easiest to fertilize) are largely deactivated and the plant must rely on deeper roots for further nutrition. Roots of plant genotypes that are efficient in mobilizing surrounding, external minerals, are not only more disease resistant but also better able to penetrate deficient subsoils and make use of the moisture and minerals there. Plants with deeper root systems are also more drought resistant. Planting such varieties, therefore, would reduce the need for fertilizers and irrigation.

Micronutrient-dense seeds are associated with greater seedling vigor and higher plant yield. The seed supplies the young seedling with minerals until it has developed a root system large enough to extract them from the soil, but seed reserves may be exhausted in nutrient poor soils before extra roots are developed to compensate for the low mineral supply. This creates a transient and critical period of deficiency when the seedling is particularly vulnerable. Pathogens and weeds may gain an advantage, and the crop may never regain its lost potential.

Although there is substantial genetic variability in the uptake efficiency of mineral micronutrients from deficient soils and in nutrient loading into seeds, micronutrient efficiency is controlled by major, single gene inheritance. The concentration and content of mineral micronutrients in seeds are the result of transport via living tissues (the phloem) from vegetative parts of the plant. Thus, seed density depends on both the micronutrient density of vegetative tissues and on the efficiency of the transport process itself. Both can be under genetic control, but there is considerable homeostasis built into the transport process; even where the soil and vegetative plant are high in micronutrients, the levels in the seed are always relatively low. An average view of genetic variation in micronutrient density is probably of the order of a factor of three, while their vegetative parts may vary perhaps one hundred times more than that.

Ponnamperuma (1982) carried out by far the most extensive survey of efficiency factors at the International Rice Research Institute (IRRI). Over a period of 10 years, some 80,000 lines from the world collection were screened for types tolerant of a number of soil stresses, including micronutrient deficiencies. Tolerant types gave a yield advantage of about two tons per hectare under any of seven different soil limitations. Ponnamperuma noted that zinc deficiency was widespread in wet rice and iron deficiency in dryland rice. Linkage of zinc efficiency to other efficiency traits (for example, manganese) is poor, suggesting that independent mechanisms and genetic control are not linked to gross root system geometry. Zinc-efficient genotypes absorb more zinc from deficient soils, produce more dry matter, and have higher grain yields, but they do not necessarily have the highest zinc concentrations in tissue or grain. Although high grain zinc concentration also appears to be under genetic control, it is not tightly linked to agronomic zinc efficiency traits and may have to be selected for independently.

3.3 Will Micronutrient-Density Change the Consumer Characteristics?

Mineral micronutrients comprise a tiny fraction of the physical mass of a seed, perhaps ten parts per million. Dense seeds may contain perhaps as many as fifty parts per million. It is not expected that such small amounts will alter the appearance, taste, texture or cooking quality of foods. Increasing the seed content of beta-carotene, which is associated with an orange or yellow color, will alter its color. This might well reduce consumer preference, but nutrition education could turn this obstacle to an advantage, as consumers could be taught that deepness of color indicates a nutrient-dense product.

3.4 Will the Extra Micronutrients in Staple Foods be Bioavailable?

An underlying cause and fundamental constraint to solving the micronutrient malnutrition problem is that non-staple foods, particularly animal products, tend to be the foods richest in bioavailable micronutrients. These are precisely the foods that the poor in developing countries cannot afford. Their diets consist mostly of staple foods, primarily cereals. For the poor, these staple foods already are primary sources of what micronutrients they are able to consume, particularly minerals. This is demonstrated by food intake data shown in Table 1 for survey populations in Bangladesh and the Philippines. Average incomes in these households range from US $45 per capita per year in the poorest 20 percent of households to $250 in the richest 20 percent of households. Thus, they are typical of the middle to lower end of the income distribution in the rural areas of these countries.

The first priority for these poor households in terms of food purchases is to obtain calories to satiate hunger. The most inexpensive sources of calories in Bangladesh are rice and wheat; in the Philippines they are maize and rice. Once a critical amount of calories are acquired from inexpensive food staples, if income is available, consumers purchase non-staple foods at the margin, particularly animal products and fruits, and to some extent substitute more expensive, more preferred food staples for inexpensive staples. Not only are food staples poor (non-dense) sources of trace minerals, but anti-nutrient (e.g., phytic acid) levels are high, which reduces the overall

Table 1: Contribution of major food groups to household food expenditures, calorie intake and iron intake for survey populations in Bangladesh and the Philippines

	Bangladesh			Philippines		
	Poorest [a]	Richest [b]	Average	Poorest [a]	Richest [b]	Average
	Percent contribution to household food expenditures					
Rice, wheat, maize	69	54	62	45	24	33
Meat, fish	9	19	14	28	39	32
Other foods	22	27	24	27	37	35
	Percent contribution to household calorie intake					
Rice, wheat, maize	87	81	84	84	70	79
Meat, fish	1	4	2	4	10	6
Other foods	12	15	14	12	20	15
	Percent contribution to household iron intake					
Rice, wheat, maize	55	43	50	43	30	36
Meat, fish	3	6	5	17	36	25
Other foods	42	51	45	40	34	39

a. Poorest 20 percent of the surveyed households.
b. Richest 20 percent of the surveyed households.

Note: The Bangladesh survey population is somewhat poorer than the Philippines survey population. One half of the Bangladesh survey population was drawn from distressed areas.

Sources: Bouis and Novenario-Reese (1997), Bouis and Haddad (1990).

bioavailability of trace minerals. Nevertheless, Table 1 reveals that primary food staples provide about 40-55 percent of total iron intakes for lower income households. If a single food staple provides 50 percent of total iron intakes for a poor population (e.g., rice in Bangladesh), then a doubling of the iron density in that food staple will increase total iron intakes by 50 percent, and tripling the iron density will double total iron intakes. One strength of a plant breeding approach that focuses on food staples, therefore, is that it relies on existing consumer behavior. The poor consume large amounts of food staples on a daily basis. If a high proportion of the domestic production of food staples can be provided by nutritionally improved varieties, nutritional status can be improved without resorting to programs that depend on behavioral change.[1]

A key issue is whether the bioavailability percentage of total iron (or zinc) intakes will remain constant or decline. Rat studies suggest that the percent of bioavailable iron (and zinc) remains relatively constant across cereal genotypes with high and low density (Welch, 1996; Welch et al.,

[1] Likewise, if nutritionally-improved varieties have unique agronomic advantages in trace mineral-deficient soils, or if these traits are incorporated into highly profitable varieties, then no behavioral change is required of farmers since profits will motivate them to adopt and produce these nutritionally-improved varieties.

1999). However, this hypothesis remains to be tested in field trials in developing countries using trace mineral-deficient human populations as subjects. A second key issue is the range of genetic diversity in iron (or zinc) density that can be identified for use in breeding programs. This will determine the maximum level to which trace mineral density can be increased. Germplasm screening under the Micronutrients Project of the Consultative Group on International Agricultural Research (CGIAR) (see section 4) suggests that the trace mineral content of cereals can be at minimum doubled in comparison to commonly eaten cereal genotypes. This would increase the iron intakes of the populations surveyed in Table 1 by about 50 percent. Iron deficiency anemia is widespread among adult women in developing countries. For the lower income households in Table 1, iron intakes for women range between 50-75 percent of recommended daily allowances. Despite well-known difficulties with determining useful benchmarks for recommended daily allowances of iron, it would seem evident that a 50 percent increase in intakes of bioavailable iron would be of considerable benefit to anemic women with such low iron intakes. Nevertheless, studies using human subjects still need to be undertaken to measure the effects of increased iron (or zinc) density in food staples on iron (or zinc) status and consequent improvements in health and productivity.

Similar reasoning applies to those staples in which provitamin A content may be enriched by plant breeding. But some differences apply. First, no agronomic advantages accrue to higher provitamin A content, so that high density will need to be bred into varieties that are otherwise high yielding. Second, the color of the final food product may change, and consumers may need to be educated about the improved nutritional content.

Reducing anti-nutrients. A breeding strategy of lowering the level of anti-nutrients (e.g., phytic acid) in the grain has often been suggested as a way to increase the bioavailability of minerals already consumed. Phytin is the primary storage form of phosphorus in most mature seeds and grains and is an important compound required for early seed germination and seedling growth (Welch, 1986; Wise, 1995). It plays an important role in determining the mineral reserves of seeds and thus contributes to the viability and vigor of the seedling produced (Welch, 1993). Graham and Welch (1996) argue that selecting for seed and grain crops with substantially lower phytin content could have an unacceptable effect on production, especially in regions of the world with soils of low phosphorus status and/or poor micronutrient fertility. Such attempts to significantly lower the anti-nutrient content of seeds and grains require a major shift in seed or grain composition. Because most of the anti-nutrients known to occur in seeds and grains are major organic constituents of these organs, they may play additional, but as yet unrecognized, beneficial roles in plant growth and human health. Therefore, they argue against a breeding strategy that attempts to increase iron bioavailability by reducing anti-nutrient content. Raboy (1996), however, has developed low phytic acid (or *lpa*) mutant varieties of maize, rice and barley. The phytic acid content of *lpa* seeds is reduced by 50-80 percent as compared with non-mutant seeds. The total amount of phosphorus remains the same – phytic acid is replaced by inorganic phosphorus, which does not bind a range of trace minerals.[2] These mutations typically have little observable effect on other seed or plant characteristics. These varieties are presently being tested for agronomic performance and effects on micronutrient status in humans.

Promoters of bioavailability. Certain amino acids (cysteine and lysine, but particularly methionine) enhance iron and/or zinc bioavailability (Hallberg, 1981). These amino acids occur in many staple foods, but their concentrations are lower than those found in meat products. A modest increase in the concentrations of these amino acids in plant foods may have a positive effect on iron and zinc bioavailability in humans. Iron and zinc occur only in micromolar amounts in plant foods, so only micromolar increases in the amounts of these amino acids may be required to compensate for the negative effects of anti-nutrients on iron and zinc bioavailability. These amino acids are essential nutrients for plants as well as for humans, so relatively small increases of their concentrations in plant tissues should not have adverse consequences on plant growth (Graham and Welch, 1996).

3.5 Are there Cheaper or Easier Sustainable Strategies for Reducing Micronutrient Malnutrition?

A plant breeding strategy, if successful, will not eliminate the need for supplementation, fortification and dietary diversification programs in the future. Nevertheless, by significantly reducing the numbers of people requiring treatment, this strategy has the promise to significantly reduce the recurrent expenditures required for these higher-cost, short-run programs.

Costs of plant breeding. To obtain a rough estimate of plant breeding costs, the example of the CGIAR Micronutrients Project may be used. This project is a multi-disciplinary effort among plant scientists, human nutritionists and social scientists. The general objective over five years is to assemble the package of tools that plant breeders will need to produce mineral- and vitamin-dense cultivars. The target crops are wheat, rice, maize, phaseolus beans and cassava. The target micronutrients being studied

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[2] When such mutants are used as animal feeds, this also avoids what has become a serious pollution problem: excretion of unutilized phytic acid.

are iron, zinc and vitamin A. The plant breeding effort can be seen as a two-stage process. The first five-year phase primarily involves research at central agriculture research stations, at an estimated US $2 million per year for research on all five crops. During this initial phase, promising germplasm is identified and the general breeding techniques are developed for later adaptive breeding. During the second phase, the emphasis shifts to national agricultural research. Total costs and duration of this second phase are difficult to estimate, but will depend on the number of countries involved and the number of crops worked on in each country. The annual cost for each country should not be more than the US $2 million per year estimated for the first phase.

Benefits to improved human nutrition. The World Bank (1994) estimates that at the levels of micronutrient malnutrition existing in South Asia, 5 percent of gross national product is lost each year due to deficiencies in the intakes of just three nutrients: iron, vitamin A and iodine. For a hypothetical country of 50 million persons burdened with this rate of malnutrition, deficiencies in these three nutrients could be eliminated through fortification programs costing a total of US $25 million annually, or 50 cents per person per year. The monetary benefit to this $25 million investment is quite high in terms of increased productivity – estimated at $20 per person per year, or a forty-fold return on an investment of 50 cents. These benchmark numbers will be used below as a basis of comparison with the benefits of a plant breeding strategy.

Calculation of benefit-cost ratios. The details of a formal cost-benefit analysis are presented in Bouis (1999). Expressed in present values, costs are about US $13 million and benefits $274 million, giving a benefit-cost ratio of over 20, which is quite favorable despite the very conservative assumptions made and despite the long time lag between investments and benefits. This last point highlights an essential difference between investments in standard fortification programs and fortification through plant breeding strategies. Standard fortification programs must be sustained at the same level of funding year after year. If investments are not sustained, benefits disappear. Such investments apply to a single geographical area, such as a nation-state. By contrast, research investments in plant breeding have multiplicative benefits that may accrue to a number of countries. Moreover, these benefits are sustainable, since as long as an effective domestic agricultural research infrastructure is maintained, breeding advances typically do not disappear after initial investments.

4 FINDINGS-TO-DATE OF THE CGIAR MICRONUTRIENTS PROJECT

Convinced that the existing scientific evidence provided satisfactory answers to the above five questions, since 1995 the Danish International Development Agency (DANIDA), the US Agency for International Development (USAID), and the Australian Council for International Agricultural Research (ACIAR) have funded exploration of the potential for micronutrient density in CGIAR germplasm banks of the major staple crops. A report was published recently for several food staples (Graham et al., 1999). A summary of these findings with respect to rice is presented below.

Rice. The findings in the rice component of the project are particularly encouraging. Iron density in unmilled rice varied from 7-24 parts per million (ppm or mg/kg) and zinc density from 16-58 ppm. Because nearly all the widely grown "green revolution" varieties were similar, a benchmark was established of about 12 and 22 ppm for iron and zinc, respectively. The best lines discovered in the survey of the germplasm collection were therefore twice as high in iron and 2.5 times as high in zinc as the most widely grown varieties today. High iron and to a lesser extent, high zinc concentration, were subsequently shown to be linked to the trait of aromaticity. Most aromatic rices, such as jasmine and basmati, are high in iron, zinc and generally in most minerals (Senadhira and Graham, 1999; Graham et al., 1997; Graham et al., 1999). The close linkage to aroma suggests iron density in rice expresses as a single gene trait since aroma is itself controlled at a single locus. As in other crops, these micronutrient density traits have been combined with high yield. A promising aromatic variety found to be high in iron, designated IR68-144, is already being tested at IRRI due to its superior agronomic and consumer characteristics. This aromatic variety has 80 percent more iron (after milling) than standard IRRI releases and is early maturing, high yielding and disease resistant. Bioavailability tests using human subjects are planned to begin in 2000. Pending the results of these bioavailability tests and agronomic tests to be undertaken by the Philippine Seed Board, IR68-144 may be ready for release to farmers in the Philippines in a few years.

Genotype environment interactions. Expression of the micronutrient-density traits has been tested over a wide range of environments, and although the environmental effect itself is strong, the genotype effect is consistent across environments and sufficient to encourage a breeding effort. Environmental factors considered by one or more of the crop programs include acid soils, alkaline soils, saline soils, acid-sulfate soils, iron-deficient soils, time of planting, field site, season, nitrogen fertilization, phosphorus fertilization, potassium status, elevation and drought stress.

5 RECENT FINDINGS ON IMPROVING THE NUTRIENT CONTENT OF RICE USING BIOTECHNOLOGY

5.1 Increasing Iron Content

Ferritin is an iron-storage protein found in animals, plants and bacteria. The ferritin gene has been isolated and sequenced in plants, including soybean, French bean, pea and maize. Recent studies show that both plants and animals use ferritin as the storage form of iron and that, orally administered, it can provide a source of iron for treatment of rat anemia (Beard et al., 1996). However, human studies with extrinsically radiolabeled animal ferritin have indicated that iron contained within the ferritin molecule added to a meal is only about half as well absorbed as vegetable iron (Martinez-Torres et al., 1976; Taylor et al. 1986) and as ferrous sulphate (Skikne et al., 1997). As yet, there have been no human studies with plant ferritin, and animal studies are not considered a good model for humans (Hurrell, 1997).

Goto et al. (1999) report improving the iron content of rice by transferring the entire coding sequence of the soybean ferritin gene into a Japonica rice. The introduced ferritin gene was expressed under the control of a rice seed-storage protein glutelin promoter to mediate the accumulation of iron specifically in the grain. The transgenic seeds stored up to three times more iron than the normal seeds. Iron levels in the unmilled seeds of the transformants varied from 13 to 38 ppm,[3] while that of the non-transformants varied from only 9 to 14 ppm. Pooled mean values were 23 ppm for transformants and 11 ppm for non-transformants. The average iron content in the endosperm of the transformant was 3.4 ppm and 1.6 ppm in the non-

[3] The authors state that the iron content in a meal-size portion of ferritin rice (approximately 5.7 mg-Fe/150 g dryweight) would be sufficient to provide 30-50 percent of the daily adult iron requirement. 5.7 mg-Fe is presumably obtained by multiplying 38 ppm by 150 g. Unfortunately, this calculation assumes that consumers eat unmilled rice. The iron added by the ferritin rice in the endosperm is 1.8 ppm (3.4 ppm minus 1.6 ppm), which when multiplied by 150 g, gives only an extra 0.27 mg Fe per meal-sized portion. Nevertheless, this alternative calculation probably understates the iron added because milling does away with much, but not all of the seed's brown outer covering (bran) that is relatively dense in iron.

In a heavy rice-eating population, an adult may consume 400 g (1,400 kcal) of rice (dryweight) a day. If the differential in iron content in milled rice is 10 ppm between an iron-dense (say 18 ppm) and normal-iron rice (say 8 ppm), this confers an additional 4 mg of iron to the diet per day, which may be a 50 percent increase over the average daily intake of a poor person who obtains 80-90 percent of their energy from rice. This underscores the importance of determining where in endosperm the iron (and other trace minerals) are deposited and how mineral levels are affected by milling.

transformant. The authors speculate that the amount of iron accumulation is restricted by the transport of iron to the ferritin molecule, rather than simply by levels of ferritin protein. It may be possible, therefore, to store larger amounts of iron in the ferritin molecule by cointegrating the ferritin gene and the iron reductase-like transporter gene.

Although results have yet to be published in a refereed journal, at a recent conference Ingo Potrykus and colleagues at the Swiss Federal Institute of Technology announced a doubling of the iron content in a rice using a ferritin gene derived from *Phaseolus vulgare* (cf. Gura, 1999). Metallothionine was also expressed in the rice grain, increasing the cysteine content seven fold. It is not known if the cysteine containing peptides formed on digestion of metallothionine in the human gut have a similar enhancing effect on iron absorption as those formed on digestion of muscle tissue (Hurrell, personal communication).

5.2 Introducing a Heat-Stable Phytase Gene Which Breaks Down Phytic Acid

The phytase level in rice is normally low. Several studies have already demonstrated the usefulness of adding phytase to the rice diets of poultry (e.g., Adrizal et al., 1996; Farrell and Martin, 1998; Martin et al., 1998). The phytase found in rice seeds will hydrolyze phytic acid if seeds are soaked in water. However, boiling destroys the phytases that occur naturally in rice. The research team led by Potrykus also reported introducing a transgene for a heat-stable phytase from *Aspergillus fumigatus*, which increased the level of phytase 130-fold. The fact that the phytase is potentially heat-stable, then, is critically important. An amino acid had been changed in the sequence to make the phytase heat stable (Pasamontes, 1997). It was also active under the conditions (pH) of digestion and degraded all the phytic acid in a very short time during model in vitro digestion. Unfortunately, after expression in the grain it was no longer stable to heat and lost its activity on boiling (Hurrell, personal communication).

5.3 Increasing Promoters

Levels of lysine, an essential but limiting amino acid in rice that might promote the uptake of trace minerals, can be increased by genetic engineering (Datta, 1999). The introduction of two bacterial genes DHSPS (dihydrodipicolinic acid sythase) and AK (aspartokinase) enzymes encoded by the *Corynebacterium dapA* gene and a mutant *E. coli lysC* gene have enhanced lysine about five-fold in canola and soybean seeds (Falco et al., 1995).

5.4 Adding Beta-Carotene

Beta-carotene, a precursor of vitamin A (retinol), does not occur naturally in the endosperm of rice. Ye et al. (2000) have reported generating a large series of transgenic plants that produce grain with yellow-colored endosperm. Biochemical analysis confirmed that the color represents beta-carotene (provitamin A). According to Ye et al. (2000), *psy* (cloned from *Narcissus pseudonarcissus*; Schledz et al., 1996), *cryt1* (cloned from *Erwinia uredovora*; Misawa et al., 1993), and the *lyc* gene have been introduced into the rice, driven by the endosperm specific glutelin promoter (Gt1). *Crt1* was fused to the transit peptide (*tp*) sequence by the pea Rubisco small sub-unit (Misawa et al., 1993) to lead the accumulation of lycopene in the endosperm plastids. This is a remarkable accomplishment considering that most traits engineered to date have only required the addition of a single gene (Guerinot, 2000). The reported level of beta-carotene in one gram of the transformed rice is 1.6 µg. Multiplying that by a daily intake of 400 grams of milled rice and dividing by a conversion ratio of 6 µg of beta-carotene for every retinol equivalent (RE) gives 107 RE, which Ye et al. (2000) state is the target level for improved nutrition. However, widely accepted RDAs for vitamin A range between 375-1,200 RE depending on age, gender and physiological status, and recent evidence suggests that the conversion factor from beta-carotene to RE varies between 12-26 to 1 (de Pee et al., 1998).[4] Nevertheless, RDAs are set relatively high by adding two standard deviations to the observed mean requirements of a nutrient for most people.

According to Datta (1999), the introduction of ferritin, heat-stable phytase and beta-carotene in rice by the Potrykus-led team has been accomplished individually in separate Japonica rices (i.e., not jointly in the same rice). These cultivars may be used in the IRRI breeding program to transfer the genes of interest to Indica cultivars from which IRRI releases are derived. Alternatively, these genes can be introduced directly into Indica cultivars using biotechnology.

[4] Ye et al. (2000) use a ration of 300 g of milled rice in their calculations but add that they are optimistic that they can reach a goal of 2 µg/g of beta-carotene in homozygous lines. In a relatively heavy-rice-eating population such as Bangladesh, non-breastfeeding pre-schoolers in rural areas might consume 250 g of milled rice per day (an RDA of 500 RE), adult women 500 g of milled rice per day (an RDA of 800 RE if not pregnant or breastfeeding), and adult men 650 g of milled rice per day (an RDA of 1,000 RE).

6 STRATEGY FOR COMBINING CONVENTIONAL BREEDING AND BIOTECHNOLOGY

What is the appropriate mix of conventional breeding techniques and biotechnology in breeding for micronutrient-dense staple food crops? Where are they complementary? Where is one approach feasible, but the other not? Table 2 summarizes some of the issues involved.

To return to two of the themes raised earlier in the paper, the fundamental advantages of breeding for increased trace minerals are that (i) agricultural productivity is not compromised, indeed is enhanced on trace mineral deficient soils, and (ii) consumer characteristics should remain unchanged. Thus, for rice, although it is fortunate that IR68-144 was "discovered" without resort to breeding explicitly for high iron, such a discovery has a relatively high probability of occurring because of the compatibility with high yields of the nutritional trait being sought. Such "discoveries" can greatly speed up the development and dissemination process and lower the cost of breeding. After milling, IR68-144 confers an 80 percent increase in iron density over modern varieties presently being released. This is about the same average advantage as reported by Goto et al. (1999) and the Potrykus group.[5] It may be possible to further elevate this 80 percent advantage by crossing various iron-dense genotypes that may have complementary, additive mechanisms for loading more iron into the seed. The two successes at adding a ferritin gene to rice reported here have not given superior results to those obtained by conventional plant breeding. Moreover, breeding is still required to move the "ferritin" trait from Japonica to high-yielding Indica rice varieties. It may be that eventually the most iron-dense genotypes can be developed using biotechnology, especially after the basic physiology of what mechanisms control translocation of trace minerals in plants is better understood. However, a specific strategy for doing so has yet to be demonstrated.

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[5] Goto et al. (1999) and Potrykus measure their iron increases against benchmarks that are the non-transformed genotypes. But are these benchmarks relatively high or low density genotypes to start with? The only figures available are from Goto et al. (1999). Their maximum value of 38 ppm in brown rice is quite high compared with all rices analyzed under the CGIAR Micronutrients Project. However, this was an analysis of only one single grain from a plant grown under laboratory conditions (iron content varies by weather and soil type). Analyses under the CGIAR Micronutrient Project are averages for randomly drawn samples of several seeds of a single genotype grown in a specific season on a specific soil. Thus, the average of 23 ppm obtained by Goto et al. (only 11 grains in total) is probably the best comparison with IR68-144, which has an iron density of 23 ppm for some plantings (Gregorio, 1999).

Table 2: Effects of different breeding strategies for micronutrient-dense staple crops

Iron deficiency	*Increasing iron content*	*Reducing phytic acid*	*Adding phytase* [a]	*Adding promoter*
Effects on plant yield	Neutral to positive	May be neg. on poor soils	Unknown	Unknown
Effects on consum. charact.	Likely no effects	In most cases, no effects	Unknown	Unknown
Benefits for human nutrition	———Substantial pending testing of bioavailability———			
		Improved bioavailability of several nutrients; but phytic acid may have positive health effects		
Zinc deficiency	*Increasing zinc content*	*Reducing phytic acid*	*Adding phytase* [a]	*Adding promoter*
Effects on plant yield	Neutral to highly pos.	May be neg. on poor soils	Unknown	Unknown
Effects on consum. charact.	Likely no effects	In most cases, no effects	Unknown	Unknown
Benefits for human nutrition	Potentially substantial pending testing of bioavailability; public health benefits suspected but not firmly established			
		Improved bioavailability of several nutrients; but phytic acid may have positive health effects		
Vit. A deficiency	*Increasing beta-carotene content* [a]			
Effects on plant yield	Unknown			
Effects on consum. charact.	Nutrition education required			
Benefits for human nutrition	Substantial, although numbers of deficient individuals are not as high as for iron and zinc			

a. Requires use of biotechnology.

We conclude that, in the short-to-medium term, conventional breeding methods may give superior results with respect to iron and zinc density as compared to biotechnology. However, the implication is not that biotechnology-related, long-term research to increase trace mineral density should be stopped. Rather, spending using either methodology is presently quite low and should be increased in view of the cost-benefit analysis presented earlier.

Three complementary or alternative approaches to increasing the bioavailability of trace minerals in the grains of food staples are listed in Table 2: (i) reducing phytic acid, (ii) introducing phytase, and (iii) increasing promoting compounds. As described earlier, low phytic acid mutants of rice, maize, wheat and barley have already been produced in which virtually all or a large portion of the phytic acid has been replaced by inorganic phosphorus. This is a promising approach in terms of improving human nutrition, although a drawback may be its agronomic performance on phosphorus-poor soils. Evidence about which compounds promote bioavailability, such as sulfur-containing amino acids, is sketchy. Until this approach is more thoroughly researched and specific compounds firmly identified as promoting bioavailability, it is probably too early to begin breeding for such compounds using conventional plant breeding or biotechnology.

A promising approach for the use of biotechnology with respect to trace minerals is to add a heat-stable phytase to rice.[6] This particular approach is not an option for conventional plant breeding and can only be pursued using biotechnology. No data exist on how adding phytase to rice would affect agronomic performance or consumer characteristics.

Turning now to vitamins, the addition of beta-carotene in rice is possible only through biotechnology. No rice has been identified with beta-carotene in the endosperm. Thus, the apparent success of Potrykus' group in this regard is quite exciting. Nevertheless, apart from breeding these beta-carotene-related genes into high-yielding varieties and assessing possible effects on plant productivity, it is already known that the beta-carotene turns the seeds yellow. How willingly will poor consumers purchase and consume yellow rice? Most people agree that without a complementary nutrition education program, consumers will not readily accept "yellow rice". Opinions differ as to the power of nutrition education to overcome culturally held preferences for white rice. It is easy to speculate either way, but no hard data are available. If a nutrition education program were successful, however, the yellow color would distinguish more nutritious rice from less nutritious rice and the disadvantage of the yellow color would be turned to an advantage.

An additional exciting possibility is that higher intakes of beta-carotene (converted to retinol after ingestion) may promote absorption of iron and vice versa. That is, there are possible synergies between higher intakes of these two nutrients (Garcia-Casal et al., 1998). There is already considerable evidence about the synergies between vitamin A and zinc intakes (Smith, 1996).

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[6] According to Preben Holm (personal communication), plant phytases have been very difficult to isolate. For cereals there are only two maize phytase genes isolated, one expressed in the seedling and the other in the root. This implies that there are virtually no tools available for gene expression analyses and for immuno detection of proteins.

7 LESSONS TO BE DRAWN

The following lessons may be drawn concerning the potential usefulness of biotechnology in helping to provide more nutritious food staples in developing countries:

1. It must be established that plant breeding is more cost-effective than alternative interventions already in place to reduce micronutrient malnutrition. This is apparently the case, in large measure because of the multiplier effects of plant breeding – a relatively small, fixed, initial investment in research may benefit the health of millions of poor people in developing countries all over the world, at the same time improving agricultural productivity on lands which are presently among the least productive.
2. There must be aspects of the breeding strategy for which biotechnology is superior to conventional breeding techniques. For rice, this is the case for adding beta-carotene-related and heat-stable phytase genes. In the long run, as more is understood about the factors driving translocation of minerals in plants, it may also be helpful for increasing trace mineral density. However, present evidence suggests that in the short-run, conventional breeding techniques to increase levels of trace minerals work as well and may be applied more quickly.
3. In those areas of plant breeding where biotechnology is superior to conventional plant breeding, it must be established that: (i) there are no serious, negative agronomic consequences associated with the characteristic being added; (ii) consumers will accept any noticeable changes in the color, taste, texture, cooking qualities and other features associated with the characteristic being added; and (iii) the characteristic being added will measurably improve the nutritional status of the malnourished target population.

The conditions under lesson three, in particular, have yet to be firmly established, but it is important not to be overly cautious. The potentially enormous benefits to the poor in developing countries in relation to costs are so high that research in this area should be vigorously pursued.

8 CONCLUSION

Biotechnology can improve consumer welfare in a number of ways not discussed in this paper. By helping to improve crop and animal productivity and thereby increasing the growth rate of supply of a range of foods, biotechnology can help reduce food prices for poor consumers. Lower cereal prices can have substantial income effects for such consumers, improving their ability to purchase non-staple foods that are rich in bioavailable minerals and vitamins. Lower prices for non-staple foods themselves, of course, also permit higher consumption of micronutrient-dense foods. Consumer-preferred characteristics of food, such as appearance, taste and color, can also be improved through biotechnology, but such research probably benefits rich consumers more than poor consumers in developing countries.

Ultimately, good nutrition depends on adequate intakes of a range of nutrients and other compounds in combinations and levels that are not yet completely understood. The best and final solution to malnutrition in developing countries is to provide increased consumption of a range of non-staple foods. By reducing the cost of producing food, biotechnology will perhaps make its most important contribution to reducing malnutrition. However, this will require several decades, informed government policies and a relatively large investment in agricultural research and other public and on-farm infrastructure to be realized.

In the medium run, a much smaller investment in breeding nutrient-dense staple foods can make a major contribution to reducing deficiencies in selected micronutrients. Because of the inherent compatibility of high yields and trace mineral density, some successes in increasing the mineral content of staples can be achieved in the short-run through conventional breeding techniques. Plant breeding is a new strategy for improving nutrition, and it is essential to make these early, nutritionally improved varieties available to farmers for commercial production. Any resulting improvements in micronutrient status must be measured to demonstrate the feasibility and practicality of plant breeding for improving micronutrient nutrition.

Once feasibility and practicality are established for specific crops and nutrients, the hope is that donor agencies will decide to accept the relatively long lead times involved in plant breeding strategies and that these agencies and agricultural research systems will adequately fund the required research. The full potential of biotechnology can then be applied to improving the nutritional content of food staples by (i) perhaps increasing mineral levels even further than is possible with conventional breeding techniques and (ii) pursuing complementary strategies, such as adding beta-carotene and heat-stable phytase genes, that are not possible using conventional breeding techniques.

REFERENCES

ACC/SCN (Administrative Committee on Coordination, Subcommittee on Nutrition) and International Food Policy Research Institute (2000): Fourth Report on the World Nutrition Situation. United Nations, Geneva.

Adrizal, P., E. Palo, and J.L. Sell (1996): Utilization of Defatted Rice Bran by Broiler Chickens. *Poultry Science* 75 (8), pp. 1012-1017.

Beard, J.L., J.W. Burton, and E.C. Theil (1996): Purified Ferritin and Soybean Meal Can Be Sources of Iron For Treating Iron Deficiency in Rats. *Journal of Nutrition* 126, pp. 154-160.

Bouis, H.E. (1999): Economics of Enhanced Micronutrient Density in Food Staples. *Field Crops Research* 60, pp. 165-173.

Bouis, H.E., and L.J. Haddad (1990): *Agricultural Commercialization, Nutrition, and the Rural Poor: A Study of Philippine Farm Households*. Lynne Rienner Publishers, Boulder.

Bouis, H.E., and M.J. Novenario-Reese (1997): The Determinants of Demand for Micronutrients: An Analysis of Rural Households in Bangladesh. FCND Discussion Paper, International Food Policy Research Institute, Washington, D.C.

Brown, P.H., Q. Zhang, and L. Ferguson (1994): Influence of Rootstock on Nutrient Acquisition by Pistachio. *Journal of Plant Nutrition* 17, pp. 1137-1148.

Cary, E.E., W.A. Norvell, D.L. Grunes, R.M. Welch, and W.S. Reid (1994): Iron and Manganese Accumulation by the brz Pea Mutant Grown in Soils. *Agronomy Journal* 86, pp. 938-941.

Datta, S.K. (1999): The Genetic Engineering Approach to Development of Nutritious Rice. Paper presented at the workshop "Improving Human Nutrition Through Agriculture: The Role of International Agricultural Research", 5-7 October, Los Baños, Philippines.

Falco, S.C., T. Guida, M. Locke, J. Mauvais, C. Sanders, R.T. Ward, and P. Webber (1995): Transgenic Canola and Soybean Seeds with Increased Lysine. *Biotechnology* 13, pp. 577-582.

Farrell, D.J., and E.A. Martin (1998): Strategies to Improve the Nutritive Value of Rice Bran in Poultry Diets, III; The Addition of Inorganic Phosphorus and a Phytase to Duck Diets. *British Poultry Science* 39 (5), pp. 601-611.

Foy, C.D. (1983): Plant Adaptation to Mineral Stress in Problem Soils. *Iowa State Journal of Research* 57, pp. 355-391.

Garcia-Casal, M.N., M. Layrisse, L. Solano, F. Arguello, D. Llovera, J. Ramírez, I. Leets, and E. Tropper (1998): Vitamin A and β-Carotene Can Improve Nonheme Iron Absorption from Rice, Wheat and Corn by Humans. *Journal of Nutrition* 128, pp. 646-650.

Gibson, R.S. (1994): Zinc Nutrition in Developing Countries. *Nutrition Research Reviews* 7, pp. 151-173.

Goto, F., T. Yoshihara, N. Shigemoto, S. Toki, and F. Takaiwa (1999): Iron Fortification of Rice Seed By the Soybean Ferritin Gene. *Nature Biotechnology* 17, pp. 282-286.

Graham, R.D., and A.D. Rovira (1984): A Role for Manganese in the Resistance of Wheat to Take-All. *Plant Soil* 78, pp. 441-444.

Graham, R.D. (1991): Breeding Wheats for Tolerance to Micronutrient Deficient Soil: Present Status and Priorities. In: D.A. Saunders (ed.). *Wheat for the Nontraditional Warm Areas*. International Maize and Wheat Improvement Center, Mexico City.

Graham, R.D., D. Senadhira, and I. Ortiz-Monasterio (1997): A Strategy for Breeding Staple-Food Crops with High Micronutrient Density. *Soil Science Plant Nutrition* 43, pp. 1153-1157.

Graham, R.D., D. Senadhira, S.E. Beebe, C. Iglesias, and I. Ortiz-Monasterio (1999): Breeding for Micronutrient Density in Edible Portions of Staple Food Crops: Conventional Approaches. *Field Crop Research* 60, pp. 57-80.

Graham R.D., and R.M. Welch (1996): Breeding for Staple Food Crops With High Micronutrient Density. Agricultural Strategies for Micronutrients, Working Paper 3, International Food Policy Research Institute, Washington, D.C.

Gregorio, G. (1999): Research on Trace Minerals in Rice. Paper presented at the workshop "Improving Human Nutrition Through Agriculture: The Role of International Agricultural Research", 5-7 October, Los Baños, Philippines.

Grubb, P.J. (1994): Root Competition in Soils of Different Fertility: A Paradox Resolved? *Phytocoenologogia* 24, pp. 495-505.

Guerinot, M.L. (2000): The Green Revolution Strikes Gold. *Science* 287, pp.241-243.

Gura, T. (1999): New Genes Boost Rice Nutrients. *Science* 285, pp. 994-995.

Hallberg, L. (1981): Bioavailability of Dietary Iron in Man. *Annual Review of Nutrition* 1, pp. 123-127.

Han, Z.H., Q. Wang, and T. Shen (1994): Comparison of Some Physiological and Biochemical Characteristics Between Iron-Efficient and Iron-Inefficient Species in the Genus Malus. *Journal of Plant Nutrition* 17, pp. 1257-1264.

Hurrell, R.F. (1997): Bioavailability of Iron. *European Journal of Clinical Nutrition* 51 (Supplement 1), pp. 4-8.

Kannenberg, L.W., and D.E. Falk (1995): Models for Activation of Plant Genetic Resources for Crop Breeding Programs. *Canadian Journal of Plant Sciences* 75, pp. 45-53.

Levin, H., E. Pollitt, R. Galloway, and J. McGuire (1993): Micronutrient Deficiency Disorders. D. Jamison, W. Mosley, A. Measham, and J. Bobadila (eds.). Disease Control Priorities in Developing Countries. Oxford University Press, New York.

Martin, E.A., J.V. Nolan, Z. Nitsan, and D.J. Farrell (1998): Strategies to Improve the Nutritive Value of Rice Bran in Poultry Diets, IV; Effects of Addition of Fish

Meal and a Microbial Phytase to Duckling Diets on Bird Performance and Amino Acid Digestibility. *British Poultry Science* 39 (5), pp. 612-621.

Martinez-Torres, C., M. Renzi, and M. Layrisse (1976): Iron Absorption By Humans from Hemosiderin and Ferritin, Further Studies. *Journal of Nutrition* 106, pp. 128-135.

McCay, B.T.S., D.M. Huber, R.D. Graham, J.D. Phillips, and K.E. Miskin (1995): Manganese Seed Content and Take-All of Cereals. *Journal of Plant Nutrition* 18, pp. 1711-1721.

Misawa, N., S. Yamono, H. Linden, M.R. de Felipe, M. Lucas, H. Ikenga, and G. Sandmann (1993): Functional Expression of the Erwinia Uredovora Carotenoid Biosynthesis Gene crtl in Transgenic Plants Showing an Increase of β-Carotene Biosynthesis Activity and Resistance to the Bleaching Herbicide Norflurazon. *Plant Journal* 4 (5), pp. 833-840.

Pasamontes, L., M. Haiker, M. Wyss, M. Tessier, A.P.G.M. van Loon (1997): Gene Cloning, Purification, and Characterization of a Heat-Stable Phytase from the Fungus Aspergillus Fumigatus. *Applied Environmental Microbiology* 63, pp. 1696-1700.

de Pee, S., C.E. West, D. Permaesih, S. Martuti, Muhilal, and J.G. Hautvast (1998): Orange Fruit Is More Effective Than Are Dark-Green, Leafy Vegetables in Increasing Serum Concentrations of Retinol and β-Carotene in Schoolchildren in Indonesia. *American Journal of Clinical Nutrition* 68, pp. 1058-1067.

Pearson, J.N., and Z. Rengel (1995): Uptake and Distribution of Zn and Mn in Wheat Grown at Sufficient and Deficient Levels of Zn and Mn During Growth Development. *Journal of Experimental Biology* 46, pp. 841-845.

Ponnamperuma, F.N. (1982): Genotypic Adaptability as a Substitute for Amendments on Toxic and Nutrient-Deficient Soils. In: A. Seife (ed.). *Plant Nutrition 1982*. CAB, Slough, UK, pp. 467-473.

Raboy, V. (1996): Cereal Low Phytic Mutants: A 'Global' Approach to Improving Mineral Nutritional Quality. Micronutrients and Agriculture, No. 2, Federation of American Scientists, Washington, D.C.

Rahman, S., G.F. Vance, and L.C. Munn (1993): Salinity Induced Effects on the Nutrient Status of Soil, Corn Leaves, and Kernels. *Community in Soil Science and Plant Analysis* 24, pp. 17-18.

Rengel, Z., and R.D. Graham (1995): Importance of Seed Zn Content for Wheat Growth on Zn-Deficient Soil, I; Vegetative Growth. *Plant and Soil* 173, pp. 259-266.

Rengel, Z., and R.D. Graham (1995): Importance of Seed Zn Content for Wheat Growth on Zn-Deficient Soil, II; Grain Yield. *Plant and Soil* 173, pp. 267-274.

Schledz, M., S. Al-Babili, J. Lintig, H. Haubruck, S. Rabbani, H. Kleinig, and P. Beyer (1996): Phytoene Synthase from Narcissus Pseudonarcissus: Functional Expression, Galactolipid Requirement, Topological Distribution in Chromoplasts and Induction During Flowering. *Plant Journal* 10 (5), pp. 781-792.

Senadhira, D., and R.D. Graham (1999): Genetic Variation in Iron and Zinc Concentrations in Brown Rice. *Micronutrients in Agriculture* 3, pp. 10-12.

Sillanpaa, M. (1990): Micronutrient Assessment at the Country Level: An International Study. FAO Soils Bulletin 48, Food and Agriculture Organization of the United States, Rome.

Skikne, B., D. Fonzo, S.R. Lynch, and J.D. Cook (1997): Bovine Ferritin Bioavailability in Man. *European Journal of Clinical Investigations* 27, pp. 228-233.

Smith, J.C. (1996): The Vitamin A – Zinc Connection. Micronutrients and Agriculture, No. 1, Federation of American Scientists, Washington, D.C.

Sparrow, D.H., and R.D. Graham (1988): Susceptibility of Zinc-Deficient Wheat Plants to Colonization by Fusarium Graminearum Schw. Group 1. *Plant Soil* 112, pp. 261-266.

Taylor, P.G., C. Martinez-Torres, E.L. Romano, and M. Layrisse (1986): The Effect of Cysteine-Containing Peptides Released During Meat Digestion on Iron Absorption in Humans. *American Journal of Clinical Nutrition* 43, pp. 68-71.

Thongbai, P., R.J. Hannam, R.D. Graham, and M.J. Webb (1993): Zinc Nutrition and Rhizoctoria Root Rot of Cereals. *Plant Soil* 153, pp. 207-214.

Welch, R.M. (1986): Effects of Nutrient Deficiencies on Seed Production and Quality. *Advances in Plant Nutrition* 2, pp. 205-247.

Welch, R.M. (1993): Zinc Concentrations and Forms in Plants for Humans and Animals. In: A.D. Robson (ed.). *Zinc in Soils and Plants*. Kluwer Academic Publishers, Boston, pp. 183-195.

Welch, R.M. (1996): The Optimal Breeding Strategy Is to Increase the Density of Promoter Compounds and Micronutrient Minerals in Seeds; Caution Should Be Used in Reducing Anti-Nutrients in Staple Food Crops. Micronutrients and Agriculture, No. 1, Federation of American Scientists, Washington, D.C.

Welch, R.M., W. House, S. Beebe, D. Senadhira, G. Gregorio, and Z. Cheng (1999): Testing Iron and Zinc Bioavailability in Genetically Enriched Bean (Phaseolus Vulgaris L.) And Rice (Oryza Sativa L.) Using a Rat Model. Paper presented at the workshop "Improving Human Nutrition Through Agriculture: The Role of International Agricultural Research", 5-7 October, Los Baños, Philippines.

Welch, R.M., M.E. Smith, D.R. van Campen, and S.C. Schaefer (1993): Improving the Mineral Reserves and Protein Quality of Maize Kernels Using Unique Genes. *Plant and Soil* 171, pp. 155-156.

Wise A. (1995): Phytate and Zinc Bioavailability. *International Journal of Food Science and Nutrition* 46, pp. 53-63.

World Bank (1994): Enriching Lives: Overcoming Vitamin and Mineral Malnutrition in Developing Countries. Development in Practice Series, World Bank, Washington, D.C.

Ye, X., S. Al-Babili, A. Klöti, J. Zhang, P. Lucca, P. Beyer, and I. Potrykus (2000): Engineering the Pro-Vitamin A (β-Carotene) Biosynthetic Pathway into (Carotenoid-Free) Rice Endosperm. *Science* 287, pp. 303-305.

Chapter 12

BIOTECHNOLOGY AND GLOBAL FOOD SECURITY: A PRIVATE-SECTOR VIEW

Walter Dannigkeit

Abstract: This paper examines biotechnology in the light of the global food and nutrition needs of the next few decades. If all available agricultural technologies – including biotechnology – are fully used, production will be able to meet global demand. Still, the regions with the highest population growth rates will likely suffer from under-supply. To improve agricultural production in these regions is a particular challenge because market forces channel research and investment away from developing countries. Private agri-business companies invest enormous resources in biotechnology research and in alliances with seed companies, but success in a market-driven environment is possible only when value is shared with other seed producers and farmers. Accordingly, the public and private sectors need to work together to exploit biotechnology's potential.

1 INTRODUCTION

Biotechnology alone will not solve the "world hunger problem", but it does have the potential to substantially improve global agricultural production in a sustainable way. Given increasing food demand and limited natural resources, this potential must be exploited – and developing countries should be included in this process. Agricultural biotechnologies are only effective, however, when carefully adapted to local conditions, and so developing countries need to have adequate research capacities and mechanisms in place. The public sector should also be able to provide legal frameworks establishing a free market environment for the private sector. In particular, a transparent regulatory system and enforceable intellectual property rights (IPRs) are essential. Efforts should also be made to address the public's concerns about the risks of biotechnology and the possible abuse of patent rights and monopolies. Accordingly, an open dialogue between all

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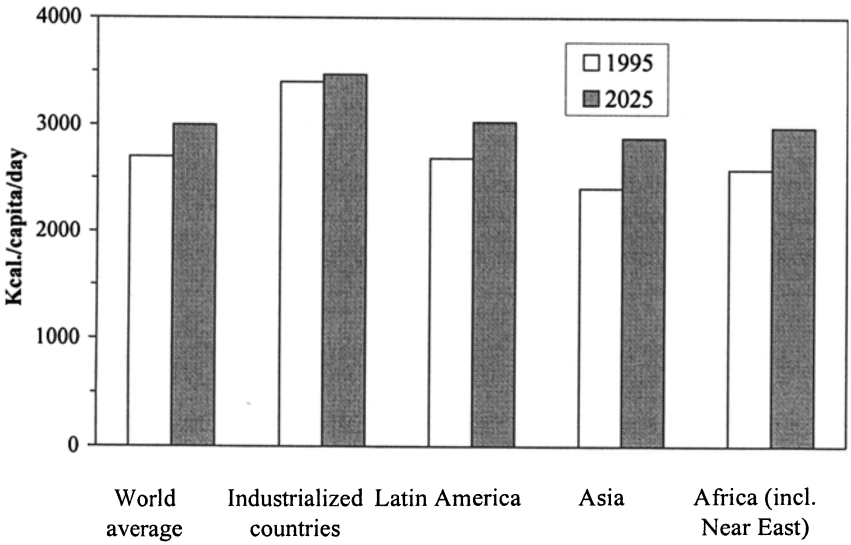
interest groups is a prerequisite for maximizing biotechnology's contribution to society.

This paper looks at biotechnology from a food security perspective. At first, it analyzes the global food and nutrition needs of the upcoming decades. A regional analysis follows, and then biotechnology's potential contribution is briefly discussed from the point of view of one private company, AgrEvo.[1]

2 GLOBAL FOOD AND NUTRITION NEEDS

The big challenge facing agricultural scientists in the next 25 years is to balance global nutrition with environmental concerns. Studies by leading scientists forecast an increase in the world's population from presently 6 billion to about 8.5 billion in the year 2025 (UN, 1999; FAO, 1999). And as population growth increases, so will consumption, from an average of 2,700 kilocalories (kcal.) per person in 1995 to 3,000 kcal. a day in 2025 (see Figure 1).

Figure 1: Calorie consumption growth



Sources: Based on Kern (1999) and data provided by the FAO.

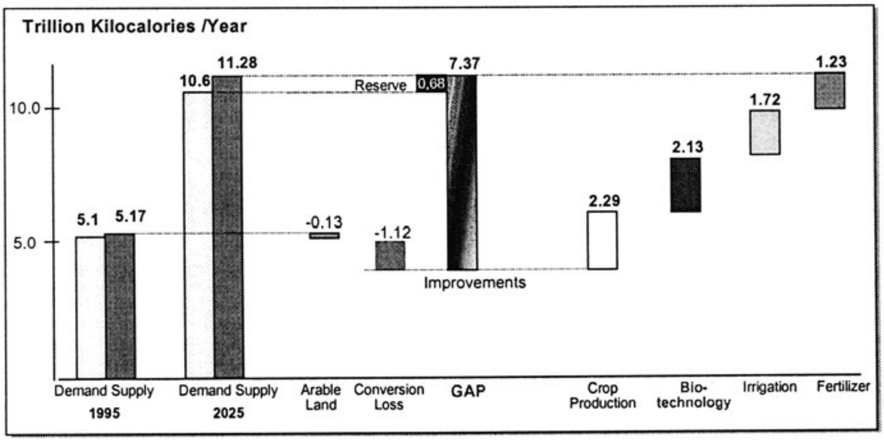
[1] With the merger between Hoechst and Rhône-Poulenc, AgrEvo became part of Aventis. The merger, however, was completed after the preparation of this paper.

People living in industrialized countries (ICs) will hardly add more calories to their diet. It is the evolution in the developing world that will be much more challenging. The daily calorie consumption in Asia, for example, is going up from 2,400 to 2,880 kcal. per person. There will also be dietary changes, as rising purchasing power shifts consumption away from vegetarian foods towards higher value livestock-based products, especially meat (Pinstrup-Andersen et al., 1999). There will clearly be a tremendous increase in calorie demand, but can the world produce enough food to meet this demand?

The agricultural progress we have achieved through plant breeding, fertilizers, crop protection and irrigation in recent decades will not be sufficient. The amount of arable land is also limited, and so there is an urgent need for new technologies to increase productivity. Biotechnology can and should be a part of the solution.

Figure 2 provides an overview of the global food supply and demand situation in 1995 and 2025. There is slight global overproduction today, but we have a problem with uneven food distribution. Furthermore, if the food demand forecasts are correct, our nutrition problems will get even worse: food production must somehow more than double in the next 25 to 30 years. If one takes into account a small reduction in arable land and a more significant conversion loss due to changing eating habits, global food production will have to grow by a staggering 140 percent. By extrapolating from the past, we can estimate that 30 percent of this necessary increase might come from better breeding and improved crop protection, including reducing post harvest losses. Another 23 percent could be achieved through better irrigation techniques, and 17 percent through the improved use of

Figure 2: Global food forecast (2025)



Source: Kern (1999).

fertilizers. The remainder of almost 30 percent will have to be accomplished through the exploitation of new technologies, and we believe that biotechnology could fill this part.

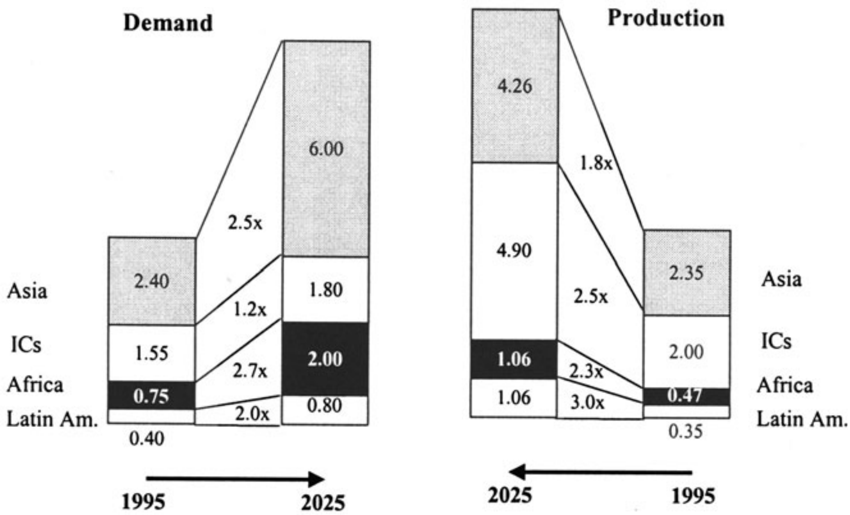
3 REGIONAL PERSPECTIVE

Food needs and production capacities vary throughout the world, and so a global picture should be supplemented with a regional perspective to fully understand how we should respond to this challenge. Figure 3 shows a realistic scenario of how food demand and production might evolve over the next generation at the regional level.

Although the production forecast is sufficient to meet global demand until 2025, the situation is fairly unbalanced at the regional level. Latin America and the industrialized countries will be able to produce a significant surplus. Despite substantial food production gains, however, Africa and Asia would still lack sufficient food supplies due to high population increases. Theoretically, these regions could import food to make up the difference, but global trade would have to increase dramatically (see Figure 4).

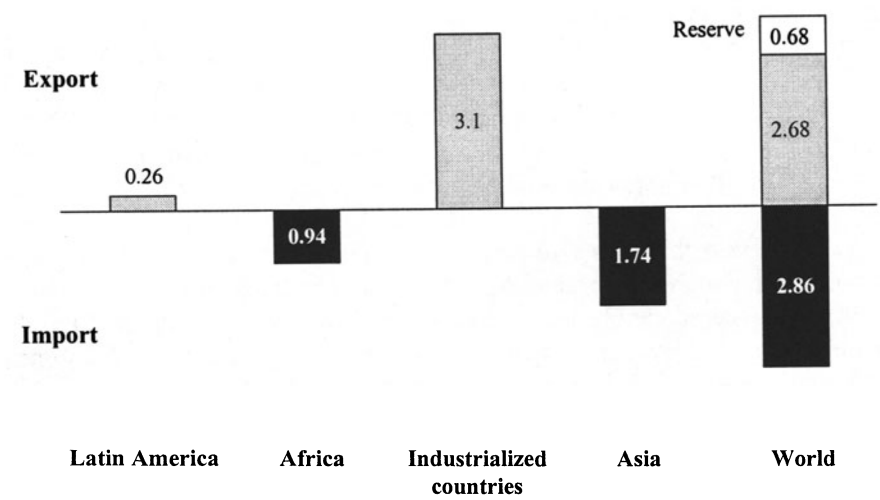
This admittedly simplistic picture should still cause concern, especially because the poorest countries in Asia and Africa might not have enough

Figure 3: Regional food demand and production (trillion kcal. per year)



Source: Kern (1999).

Figure 4: Global and regional agricultural trade in 2025 (trillion kcal. per year)



Source: Kern (1999).

purchasing power to import the food they will need at commercial prices. We must make sure that the situation described never becomes reality. The technology to prevent this catastrophe is available; the challenge is to ensure that countries with large food requirements will be able to increase their agricultural production. Biotechnology is not a panacea, but it can make a significant contribution. Improved crop varieties can be tailored to meet very diverse needs and environments anywhere around the world. Some preliminary examples of biotechnology's benefits are given below. Although they refer primarily to industrialized countries, these examples are also relevant to the developing world.

4 BIOTECHNOLOGY EXAMPLES

Transgenic cotton with insect resistance was introduced in the USA in 1996. The *Bacillus thuringiensis* (Bt) gene in this transgenic cotton endows the plant with internal protection against some damaging insects, and this provides important advantages for farmers, such as more flexible crop management and higher yield security. Farmers clearly experienced significant benefits, for within a time period of only four years these varieties made up a big part of total US cotton production. Farmers in developing countries can expect similar advantages. And because gene technology can deliver solutions that are entirely integrated in the seed – without the need for farmers to learn additional technology skills – these varieties can readily enter into traditional farming systems.

In food commodities, biotechnology enables us to realize new qualities or properties in crops such as rice. These include insect resistance, virus resistance, bacterial and fungal resistance, and aluminum tolerance. Scientists will also be able to increase yields and even improve vitamin levels, as recently reported with vitamin A enhanced rice (Potrykus et al., 1999).

Transgenic techniques also facilitate the development of hybrid varieties in crops for which the production of hybrids has been difficult. A case in point is transgenic canola in Canada, where biotechnology increased yields to a new high. Today, canola hybrids produce 10-15 percent more than open-pollinated varieties, and in the near future this figure will rise to 30-35 percent without additional inputs (such hybrids are already being tested in the field).

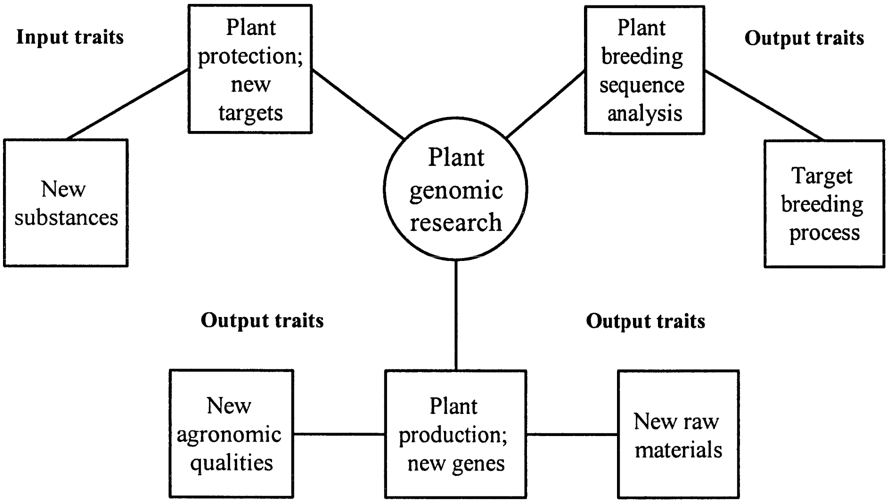
These examples show that biotechnology can improve crop productivity by safeguarding and increasing the yields. So far, agricultural biotechnology products are expressing mainly agronomic traits, such as herbicide tolerance, insect resistance, and hybridization systems. The next wave of technology products, however, will be more related to food quality and food processing characteristics, including enhanced vitamin contents and healthier, more nutritious oils and starches. Between 2005 and 2010, genetically modified plants will also produce improved raw materials for the pharmaceutical and chemical industries, such as vaccines and biodegradable plastics.

It must be stressed, however, that biotechnology will only be as effective as socioeconomic and political conditions allow. To make biotechnology broadly effective, we need to improve acceptance of the technology and enhance the transfer of know-how. Mistrust, fear or a lack of understanding will slow down this process, and so we should work hard to establish a transparent dialogue based on personal contacts. This is the best way to build trust and understanding. Such a dialogue needs to be strengthened, and barriers between the different interest groups must be reduced to support better collaboration between the public and private sector for the benefit of all.

5 AGREVO'S PHILOSOPHY AND PERSPECTIVE

As a crop production company, AgrEvo's challenges are to focus on a limited number of crops, improve research and development (R&D)

Figure 5: Plant genomic research, the central R&D tool



efficiency, develop integrated solutions for sustainable agriculture, and capture value added through its technologies. Out of AgrEvo's R&D budget, a figure approximately 12 percent of sales, 25 percent is invested in biotechnology. Investments in plant genomic research are expected to provide information about new modes of action targets in crop protection, to create new substances and raw materials, to provide a more targeted breeding process, and to discover new genes responsible for new agronomic qualities (see Figure 5). Our investments aim to create value through faster R&D with a clear focus on priority crops. In order to test and develop new biotechnologies and to recover value we have to invest in seed companies on a limited scale, but we also have to license these technologies to other seed producers. We operate in a market-driven environment steered by economics, and we can only be successful when we share added value with farmers and other seed producers.

We believe that biotechnology is a safe technology. It can make a powerful contribution to improving crop production, one that would help preserve the environment and foster human health. It has great potential to increase yields in agricultural production, to improve the nutritional content

of our food and feed, and to reduce conversion losses during food processing and handling. The highest food needs are in developing countries, and we are all challenged to ensure that available technologies are successfully applied there. Governments and the public and private sectors have to work together to fully exploit biotechnology's potential.

REFERENCES

FAO (1999): *The State of Food Insecurity in the World 1999*. Food and Agriculture Organization of the United Nations, Rome.

Kern (1999): An die Grenzen des Notwendigen; Biotechnologie als integraler Bestandteil nachhaltiger Landwirtschaft im 21. Jahrhundert. Hoechst Schering AgrEvo GmbH, Frankfurt.

Pinstrup-Andersen, P., R. Pandya-Lorch, and M. Rosegrant (1999): World Food Prospects: Critical Issues for the Early Twenty-First Century. 2020 Vision, Food Policy Report, International Food Policy Research Institute.

Potrykus, I., P. Lucca, E. Xudong, S. Al-Babilli, R.H. Hurrel, and P. Beyer (1999): Contributions to Food Security by Genetic Engineering with Rice. Paper presented in the general meeting of the International Program on Rice Biotechnology, Rockefeller Foundation, Phuket, Thailand.

UN (1999): *World Population Prospects: The 1998 Revision*. United Nations, New York.

Chapter 13

AGRICULTURAL BIOTECHNOLOGY AND THE SEED INDUSTRY: SOME IMPLICATIONS FOR FOOD PRODUCTION AND SECURITY

Suri Sehgal

Abstract: Biotechnology has the capacity to boost food production and promote sustainable agricultural development on high and low potential lands. Since seed is the delivery vehicle for agricultural biotechnology, this technology can only benefit farmers if they have access to quality seed. While most developed countries have an experienced and mature seed industry, adequate seed supply is mostly sub-optimal in the developing world. Private-sector activities are particularly hampered by institutional constraints. And so promoting a vibrant private-sector seed industry with access to value-enhancing appropriate biotechnologies could help ensure food production and security as well as healthy agricultural communities in developing countries.

1 INTRODUCTION

Biotechnology has the capacity to boost food production and to promote sustainable agricultural development. This paper reviews the key role of the seed industry in bringing the benefits of agricultural biotechnology to farmers, stressing the importance of a vibrant seed industry for food production and security in the developing world. For this line of reasoning, certain premises should be clarified in advance. First, in the developing world as elsewhere, food security means that people have access at all times to enough food for an active, healthy life. Second, ensuring such access to food in the developing world requires sustainable agricultural development on both high and low potential lands. Third, seed is the delivery vehicle for agricultural biotechnology and the basic input for agricultural development.

An indigenous seed industry, therefore, one that addresses the needs of farmers of both high and low potential lands, is essential for food production

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and security in the developing world. Because seed is the delivery vehicle, this technology can only benefit poor farmers if they have access to quality seed. While some developing countries will benefit from agricultural biotechnology strictly as seed end-users, others can utilize technology as such. That is, they can benefit from technology transfer for use in crops and varieties of their own choosing. The paper at first examines the evolution of the seed industry over the last decades in an international context. Then certain policy issues are discussed in relation to the development of an efficient local seed industry in developing countries.

2 FIRST THE SEED

Seed is the primary delivery system for genetic improvements, whether added through classical breeding or new gene technologies. And so seed will always be a critical component in any strategy to improve agricultural output. In fact, seed is the hub around which all other strategies to improve productivity revolve. Improved farming techniques, agrochemicals and machinery are only as effective as the germplasm they support. This means that farmers everywhere require a secure source of good quality seed.

The seed that farmers require must be extensively evaluated at the local level prior to its large-scale release and it must be bred for the areas in which it is to be grown. Furthermore, an improved hybrid or variety is useless if its seed does not reach farmers in sufficient quantity, quality and purity. To meet their particular needs, farmers in the developing world require a local industry involved in breeding, producing and distributing seeds. Additionally, since many crops of importance in the developing world are not of interest to multinational seed companies – even those operating in developing countries – it is important to support the development of an indigenous public- and private-sector seed industry. Since seed is first, such support will help ensure agricultural development, food production and food security.

3 SEED AND AGRICULTURAL DEVELOPMENT

In the past, both the public and the private sector have contributed significantly to agricultural development through research on hybrids and open-pollinated crops. In particular, the public-sector seed industry played a key role in the diffusion and spread of new high-yielding varieties (HYVs) and associated high-input production technologies. The development and promotion of HYVs by the International Agricultural Research Centers

(IARCs) led to dramatic increases in food production in the areas to which they were transferred. This is what has been referred to as the "green revolution". For example, the development and transfer of HYVs of wheat and rice by the International Maize and Wheat Improvement Center (CIMMYT) and the International Rice Research Institute (IRRI) in the 1960s led to dramatic increases in food production in the high potential lands of Asia, Latin America, and to a lesser extent Africa (Conway, 1998). The plant breeders at CIMMYT and IRRI substantially increased the potential yield of wheat and rice by developing dwarf varieties with stiff straw that could hold more grain in the panicle. This boosted the harvest index (i.e., the percentage of the plant's mass that is grain) by about 50 percent over traditional tall varieties.

Similarly, the development and transfer of hybrid corn by the private sector from the USA to Europe in the late 1950s and early 1960s revolutionized maize production in Europe. The average yield of new hybrids in certain areas of Europe (e.g., the Po valley in Italy, the Danubian basin of central Europe) was even higher than in the USA, where hybrid technology had been developed. This was in part due to less disease pressure in these areas, better agroclimatic conditions and superior field management. In Asia, Latin America and Africa, the development of hybrid corn by the IARCs led to similar production increases.

Increased production of feed grain hybrid sorghum was achieved by transferring HYVs and production technologies from the USA (Texas) to Latin America. In India and Africa, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and different national agricultural research systems have ensured the same for food grain sorghum and millet. Finally, public-sector hybrids have revolutionized rice production in China. Hybrid rice presently accounts for roughly half of China's rice area. These hybrids yield an average 6.8 tons per hectare, compared to 5.2 tons per hectare for conventional varieties. The private sector is now playing a major role in the spread of hybrid rice from China to other countries in Asia, particularly in India, the Philippines and Vietnam (Sehgal, 1992).

4 SEED INDUSTRY: STRUCTURE AND PRINCIPLES

Evidently, seed improvement and productivity gains in the past have resulted from both public- and private-sector research and development (R&D). Going forward, it is likely that the private sector will play an increasingly important role in developing countries. To understand the importance of an indigenous private seed sector in developing countries, it is useful to consider the structure of the seed market today. There are essentially two broad segments within the seed market: the hybrid and the non-hybrid.

The hybrid seed segment is characterized by high R&D costs, high prices and high margins. It is largely controlled by the private sector. The non-hybrid seed segment is characterized by low R&D costs, low prices and low margins. It is primarily in the public sector in developing countries and in the private sector in developed countries. An indigenous private seed industry will only grow stronger in developing countries when it can protect its research results and recover the value of the investments through adequate pricing.

There are, in fact, four basic principles on which the private seed sector operates:

1. Breeding and new gene technologies must create significant value in the products.
2. Protection of the products must be possible.
3. Industry must be able to recover part of the value through adequate pricing.
4. Farmers must significantly benefit from new products. They should be able to retain a great portion of the added value to justify paying higher prices for value-added seed.

The expansion of a private seed sector in developing countries is hampered by certain constraints. These include inadequate legislation for technology and variety protection; restricted access to new technologies; public-sector pricing subsidies; complex variety notification, registration and seed certification procedures; seed and germplasm import restrictions, including quarantine laws; and infrastructure deficiencies. Removing or modifying these constraints would provide better growth options for the private seed sector in developing countries.

Because quality research is time-consuming and cannot be switched on and off at will, proper seed development requires a long-term perspective from the entrepreneur. This means that seed enterprises expanding into new crop areas, including indigenous crops, have an advantage over new startup companies as success is more likely when building on an existing, successful program.

The private-sector seed industry is in an early stage of development in most developing countries, though elsewhere it is beginning to enter into a noticeable growth phase. New companies are being created, and others are expanding the scope of their business.

In contrast, the seed industry in developed countries is mature and in the process of consolidating and restructuring as a result of new technologies and freedom to operate issues (Sehgal, 1996). Speed to market and being first with differentiated products is the key to success. In addition to classical breeding, seed companies are creating value with molecular breeding, genetic engineering of input and output traits, and most recently, with advances from structural and functional genomics (see the paper by Christian Jung in this book for a description of the different techniques). Seed companies with access to technology are stacking new traits in varieties and hybrids to gain competitive advantage. To market these products we are seeing the emergence of integrated suppliers, which combine various interrelated inputs and provide them to farmers. For their part, farmers are using increasingly sophisticated management tools, including precision farming, to get the full value of their inputs. Finally, the commercial buyers of farm commodities are turning to identity-preserved production and contract farming. This trend is significantly increasing in the developed world.

5 SEED AND FOOD PRODUCTION AND SECURITY

Ever increasing populations are placing extreme demands on the world ecosystem. The global population has grown from approximately 1.6 billion at the beginning of this century to over 6.0 billion at present, and this is expected to grow to about 8 billion by 2025-2030 (UN, 1999). Of those 8 billion, 6-7 billion people will live in developing countries. Whether we can produce enough to feed 8 billion people and also reduce the number of undernourished is a matter of concern and debate. Much of the progress to date in meeting global food needs can be attributed to the green revolution. Despite criticism leveled against it, the green revolution did substantially raise crop yields and prevented serious food shortages in many developing countries. However, the technological advantage offered by HYVs and associated production technologies has been largely confined to high potential lands located in irrigated regions and areas with adequate rainfall. Even on these lands, however, wheat and rice yield increases are showing signs of decline. Biotechnology could help to stop and reverse this trend.

But ensuring adequate supply is only part of the food security challenge; ensuring access is at least equally important. In the developing world, 60-70 percent of the poor live in rural areas. These areas are resource poor, highly heterogeneous and risk prone. In areas that are humid or sub-humid, and in the semi-arid tropics and subtropics, the farming systems are complex, the soils fragile and the weather very erratic. These are also the regions most likely to be negatively impacted by global warming. The worst poverty is actually found in arid and semi-arid zones and in steep hill-slope areas that are ecologically unstable. Low rainfall and limited potential for irrigation limit agriculture in these areas. New biotechnologies, including those conferring tolerance to abiotic stress, can help to bring food production stability in low potential areas. Careful planning of land use – considering what land to employ for high-yield agriculture while retaining marginal or poor land for non-agricultural use or wildlife habitats – is also required. If this can be achieved, it could trigger a green revolution in these areas.

This paper has tried to demonstrate that seed is basic to agricultural development and that an indigenous, viable seed industry is essential for food production and security in the developing world. In the past, both the public and private sectors have been extremely important in ensuring that farmers in the developing world have access to high quality seed. Both sectors should continue to play their valuable roles in the future. For the seed industry to grow significantly in the developing world, however, private-sector participation will need to increase. This is because the private sector is best placed to develop and commercialize some of the new biotechnologies that are already finding their way into markets in the developed world. To promote access to such technologies in the developing world will require certain policy changes.

Developing countries must guarantee access to high quality seed to their farmers against a background of increasing populations and shrinking natural resources. Because developing counties are highly agricultural, there is currently no alternative source of livelihood for communities in these areas. Ensuring the well-being of agricultural communities, therefore, requires an emphasis on enhancing sustainable agriculture. Additionally, because of the sorts of crops grown in developing countries, food security requires significant local food production, which again requires high quality seed. Promoting a vibrant private-sector seed industry, with access to value enhancing appropriate technologies, can therefore help ensure food production and security, as well as healthy agricultural communities.

REFERENCES

Conway, G. (1998): *The Doubly Green Revolution: Food for All in the 21st Century.* Cornell University Press, Ithaca, NY.

Sehgal, S. (1996): IPR Driven Restructuring of the Seed Industry. *Biotechnology and Development Monitor* 29, pp. 18-21.

Sehgal, S. (1992): Opportunities in Hybrid Rice Development. *Seed World*, December Issue.

UN (1999): *World Population Prospects: The 1998 Revision*. United Nations, New York.

Chapter 14

A DANGER TO THE WORLD'S FOOD: GENETIC ENGINEERING AND THE ECONOMIC INTERESTS OF THE LIFE-SCIENCE INDUSTRY

Christoph Then

Abstract: Based on a few individual cases, proponents of biotechnology claim that agricultural biotechnology innovations can provide specific technical solutions to the world's food insecurity problems. In this paper, however, it is argued that genetic engineering in general, and life-science companies in particular, have a much more far-reaching and systematic influence on the global food supply than can be seen from such isolated cases. It is hypothesized that genetic engineering, capitalization and monopolization go hand in hand. As a result, existing infrastructures and forms of innovation and knowledge stand to be completely transformed and in part destroyed. In addition to the risks of modern biotechnology for consumers and the environment, the world's food would also become increasingly dependent on the economic goals of a small handful of corporations.

1 INTRODUCTION

The international discussion about genetic engineering's contribution to securing the world's food supply draws mainly on particular cases and certain newly developed high-yielding varieties. Based on this information, proponents claim that genetic engineering can provide specific technical solutions to food insecurity problems. In this paper it is claimed that genetic engineering in general, and life-science companies in particular, have a much more far-reaching and systematic influence on the global food supply than can be seen from a few isolated cases.

Experts talk of the development of agricultural genetic engineering not as "technology-driven" but as "market-driven". In other words, what matters most in deciding to use genetic engineering in many cases are not special

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technological demands but general considerations about market strategy. For example, under the heading "Industrial Strategies and Constraints", an OECD (1992) report on agricultural biotechnology states: "The main focus of attention in this sector has been the reorganization of the seed market, leading to greater integration with the agrochemicals sector…. Among the marketing strategies for new products, the traditional gene technology supplier option has become vulnerable and is giving way to the strategy of controlling seed markets, or, more importantly, the strategy of moving further downstream into crop output markets, in order to capture the industrial value added."

Genetic engineering is increasingly detached from its real scientific context; instead, it functions to open up markets across the whole area of food production. Intellectual property rights (IPRs) have put biological resources in a very new context. For as soon as genetic engineering is used, patents enable time-limited monopolistic claims – which in many cases stretch all the way from planting in fields to selling in supermarkets – to be successfully made. Once implanted, the manipulated gene provides built-in copyright protection, reaching far beyond its actual technical contribution to cover technological tools, seeds, and to some extent agricultural commodities. Genetic engineering, therefore, serves as a vehicle for implementing new monopolistic arrangements.

2 CAPITALIZATION AND CONCENTRATION OF THE SEED MARKET

In 1998, 60 percent of the world market for seeds was controlled by just 35 companies (there are a total of some 1,500; No Patent on Life, 2000). According to the business-consulting firm McKinsey, the number of seed producing companies that are active in genetic engineering decreased from more than 30 in 1990 to only 7 big enterprises in 1997 (Metzger, 1998).

In the future, the seed market will play an even more important role in enforcing the market strategies of multinationals since patent claims could limit market access for small firms and newcomers. Genetic engineering, capitalization, and monopolization go hand in hand. Financially strong agrochemical and food companies will purposely divide the seed market between themselves without great effort, and the seed sector will become an integral part of the life-science industry. From the point of view of agrochemical interests, this development is a strategic necessity. The world market volume for agrochemicals amounts to about US $28 billion, whereas the volume of the total seed market is estimated at $30-50 billion. Of that, only about one-third are commercially traded (Rabobank, 1996). This figure vividly demonstrates the enormous growth potentials for the commercial seed industry, particularly in developing countries.

A fierce struggle for shares in these markets began long ago. One of the central means of gaining large market shares is the patent which, I claim, destroys functioning legal systems and secures access to developing-country agriculture for foreign economic and capitalistic interests. If the predictions of a worldwide shortage of food in the near future prove true, strategies that enable access to the world's food resources would acquire a fairly new dimension. The increasing market concentration must also be seen against this background.

3 THE GREAT MERGER RUSH

The struggle for the best market positions is already far advanced. Monsanto in particular has been buying up all kinds of firms. Calgene, which produced tomatoes with delayed ripening, sustainable raw materials, and cotton, and Agracetus, a company that held important patents on soybeans, rice, and cotton, were acquired by Monsanto in 1995. In addition, a merger was made in 1996 with DeKalb Seeds – one of the biggest seed-producing firms. Holden's Foundation Seed, a strategically important company in the seed market was bought up for US $1 billion in 1997. In 1998, DeKalb was completely acquired for $2.3 billion. Monsanto also bought the international seed business unit of Cargill for $1.4 billion. In 1997/98 Monsanto spent a total of US $8 billion – equivalent to the company's whole turnover during these years – on acquisitions and alliances. As a result, Monsanto became the world's second largest seed company. It now controls over 80 percent of the US market for cotton, 33 percent for soybeans, and 15 percent for corn (RAFI, 1998). Indeed, to obtain the US antitrust authorities' approval for the acquisition of Delta & Pine Land in 1999, Monsanto had to sell its own cotton subsidiary, Stoneville.[1] Finally, Monsanto decided to merge with the drug company Pharmacia and Upjohn in December 1999.

Monsanto's biggest competitor in the global seed market is Pioneer Hi-Bred International. Pioneer Hi-Bred controls large parts of the international seed market, especially in soybeans and corn. After DuPont paid US $1.7 billion in 1997 for a 20 percent share in the company, Pioneer Hi-Bred was completely taken over by DuPont for $7.7 billion in 1999.

[1] Still, the purchase of Delta & Pine Land by Monsanto has later been rejected due to US antitrust regulations.

The European market is also feverishly merging. AgrEvo, a joint venture of the agricultural sections at Schering and Hoechst, bought Plant Genetic Systems (PGS) for US $800 million. In 1999, Hoechst and Rhône-Poulenc merged to form the new life-science company Aventis. The giant corporations of Ciba-Geigy and Sandoz celebrated their marriage in 1996, when Novartis was created. The dowry included a comprehensive patent on genetically modified corn. In the pesticide sector, a section of the US company Merck was acquired by Novartis for 1.5 billion German marks in 1997. In 1997/98, Novartis was the third biggest seed company in the world. After the merger of its agricultural branch with AstraZeneca, announced in 1999, the number one company in the world market for agrochemicals will be the emerging company Syngenta, followed by Aventis, DuPont, and Monsanto (Hoffritz, 2000).

The merger between DuPont and Pioneer Hi-Bread and the development of Monsanto, Hoechst, and Novartis clearly show how far agrochemical companies have penetrated the seed market.

4 FOOD CHAIN CLUSTERS

But not only the seed market is at stake. New "food chain cluster" collaborations between the agrochemical enterprises and grain handling and processing companies are gaining control of the whole agricultural chain from seed to food and feed. A study carried out by the University of Missouri (Heffernan, 1999) provides some details about these related alliances, such as those between Monsanto and Cargill or between Novartis and Archer Daniels Midland (ADM):

"In a food chain cluster, the food product is passed along from stage to stage, but ownership never changes and neither does the location of the decision-making. Starting with the IPRs that governments give to the biotechnology firms, the food product always remains the property of a firm or cluster of firms. The farmer becomes a grower, providing the labor and often some of the capital, but never owning the product as it moves through the food system and never making the major management decisions. The system is still evolving and it is not yet possible to determine how many clusters may evolve, but experiences in other economic sectors, like the auto industry, suggest we seldom see monopolies evolve. Even at the global level, where there are no antitrust regulations, oligopolies, not monopolies, tend to emerge. We are predicting the development of four or five food clusters, because the number of clusters will be heavily influenced by the number of firms who have access to the IPRs. The underlying assumption here is that biotechnology will be accepted by most nations of the world, an assumption that may not be valid, because this acceptance is still in question in some countries. We will make this assumption here because the monopoly power that accompanies the IPRs that leads to control of the gene pool will be most difficult for any new or emerging cluster to obtain."

5 SYSTEMATIC ACQUISITION OF AGRICULTURAL PLANTS

Most of the agricultural plants we use have their origin in the countries of the South. The history of our agricultural plants is closely interwoven with the North's colonization and its systematic forays through the centers of biological diversity (cf. Flitner, 1995).

The application of genetic engineering and patenting puts this on a new scale. Some companies are working systematically to analyze the genetic make-up of those varieties most frequently used in the world (cf. Thomas et al., 1999). Pioneer Hi-Bred, for instance, concluded a contract worth over US $16 million with the Human Genome Science databank to analyze the genetic material in corn. The results of this collaboration are expected to be protected by patents.

All the following cooperative agreements were made in 1998 alone between agrochemical companies and genome-analysis institutes, with the aim of analyzing, evaluating, and patenting the maximum possible genetic material of the plants involved (cf. Ratner, 1998):

- AgrEvo and Gene Logic (exclusive 3-year contract for US $45 million),
- DuPont and CuraGen,
- Novartis and NADI (US $600 million to be invested over ten years),
- Zeneca and Alanex,
- Monsanto and InCyte Pharmaceuticals.

AgrEvo, DuPont, Novartis, Zeneca, and Monsanto are among the ten biggest agrochemical and seed companies in the world, and their activities and cooperative agreements affect both the countries of the southern and the northern hemisphere.

These companies are at present increasingly striving to control the seed market in developing countries. For example, Monsanto started initiatives to gain direct access to the seed market in India, establishing special alliances with the reputable Indian Institute of Sciences in Bangalore and the biggest public seed-growing company in India, Mahyco. The reason for this is that the major growth potentials for agricultural seed marketing are lying in the developing world. As mentioned above, currently only a small fraction of the total seed amounts used by farmers are purchased on a commercial basis. Around 80 percent of sowing in Asia, Africa, and South America uses the farmers' own retained seeds from the previous harvest. To a very large extent, patent protection can put an end to re-sowing and farmers using their own crops as a source for seed. In addition, the plants' natural reproductive ability can be blocked by genetic changes, making it biologically impossible for farmers to re-sow their own crops. The US company Delta & Pine Land, has applied for a patent for this purpose in Europe (WO96/04393). This so-called "Terminator-Technology" has been heavily attacked internationally from many sides. Nevertheless, a Terminator patent is expected to be granted in Europe. Greenpeace made public that the European Patent Office gave its written consent to PGS to grant patent EP 412 006 which covers plants with female sterility (cf. Then and Schweiger, 1999). Whether it is the result of licensing contracts, the Terminator-Technology, or the increased use of hybrid seeds, the effect on farmers will be the same: every year they will have to buy their seed anew. China, Brazil, Mexico, Morocco, India, and Pakistan are regarded as major markets for the expansion of trade in commercial seeds.

6 BIOPIRACY A NEW FORM OF COLONIALISM

Vandana Shiva, an Indian scientist, author and Alternative Nobel Prize winner of international repute, is one of the major critics of this development. "Since colonial times", she says (Shiva, 1995), "land, resources and people's rights in developing countries have been usurped by the colonial masters. Today this process is taking place more subtly. The northern hemisphere's multinational corporations are trying to obtain exclusive rights to the Third World's biodiversity and the genetic resources of its plant life. They are seeking to expand IPRs through institutions like the General Agreement on Tariffs and Trade (GATT), in what is in effect monopolizing ideas and debasing the knowledge of people in the Third World. IPRs are the key to absolute possession and control of the Third World's resources and markets."

7 UNEQUAL WEAPONS

Favoring the industrialized countries of the North, patent law lays down what an innovation is and which forms of IPRs are to be recognized, thus determining who might, and who might not, profit in the hunt for "green gold". Only innovations discovered in a laboratory are protected under current patent laws. Knowledge collectively acquired, and the innovations connected with it, e.g. the preservation of adapted agricultural varieties, remain unprotected.

For financial and legal reasons, companies operating internationally can also easily control patents. Patents can be registered for a hundred countries all at once (so-called "world patents", processed at the European Patent Office). On the other hand, effectively registering patents is almost impossible for farmers or for those with medical training in developing or newly industrialized countries. About 97 percent of the patents issued worldwide belong to companies that have their head offices in industrialized countries (UNDP, 1999).

The extent of genetic engineering corporations' patents can be seen, by way of illustration, from the Monsanto company's patent (EP 546 090) on herbicide-resistant soybeans. This applies to genetically modified plants which have been made resistant to the company's own weed-killer, Roundup® (glyphosate). The following kinds of plants are listed: "corn, wheat, rice, soybeans, cotton, sugar-beet, canola, flax, sunflower, potato, tobacco, tomato, lucerne, poplar, pine, apple and grape." The patent also applies to the agricultural cultivation of the plants. According to the patent text, "Planting these...glyphosate-tolerant plants is also patented, as is applying an adequate amount of glyphosate herbicide to agricultural plants and weeds."

8 IMPACTS OF GENETIC ENGINEERING

An assessment of the impact of genetic engineering on world food security must take a number of aspects into account:

- In its scientific methodology, plant cultivation is increasingly oriented not on the diversity of varieties or species but on specific genes.
- Genetic engineering will accelerate the loss of agrarian diversity (i.e., the advancing "genetic erosion" which could already be observed during the last decades).
- The technology reduces biological diversity to economically taxable genetic resources.
- It contributes to the ousting of traditional farming cultures and regionally organized systems by globalizing markets.
- It reinforces the debasement of biological innovations through copyrights and patents, which only reward what is "discovered" in industrial laboratories.

- The technology leads to an increasing monopolization of the whole chain of food production from seeds to supermarkets.

Since genetic engineering, in my opinion, means completely transforming and in part destroying existing infrastructures and forms of innovation and knowledge, it is in a special sense a hazardous technology. The hazards lie not only in new risks for consumers and the environment, but in the world's food becoming increasingly dependent on the economic goals of a small handful of corporations.

REFERENCES

Flitner, M. (1995): *Sammler, Räuber und Gelehrte; die politischen Interessen an pflanzengenetischen Ressourcen 1895-1995*. Campus Verlag, Frankfurt.

Heffernan, W. (1999): Consolidation in the Food and Agriculture System. Report to the National Farmers Union, Department of Rural Sociology, University of Missouri, Columbia.

Hoffritz, J. (2000): Kopfweh in Basel. *Die Zeit*, German Newspaper, 5 January, p. 18.

Metzger, R. (1998): Die großen Sämänner kommen. *Die Tageszeitung*, German Newspaper, 21 January, p. 8.

No Patent on Life (Kein Patent auf Leben) (2000): Statements retrieved from the internet: www.keinpatent.de.

OECD (1992): *Biotechnology, Agriculture and Food*. Organization for Economic Cooperation and Development, Paris.

Rabobank (1996): *The World Seed Market*. 2nd Edition. Rabobank International Marketing, The Netherlands.

RAFI (1998): Seed Company Chart, July/August. Rural Advancement Foundation International, Winnipeg.

Ratner, M. (1998): Competition Drives Agricultural's Genomic Deals. *Nature Biotechnology* 16, p. 810.

Shiva, V. (1995): *Monocultures of the Mind: Perspectives on Biodiversity and Biotechnology*. Third World Network, Penang.

Then, C., and T. Schweiger (1999): Gene, Monopole und Life Industry, Eine Dokumentation über die Patentierung von Leben. Greenpeace Germany, Retrieved from the internet: www.greenpeace.de

Thomas, S.M., M. Brady, and J.F. Burke (1999): Plant DNA Patents in the Hand of a Few. *Nature* 399, pp. 405-406.

UNDP (1999): *Human Development Report 1999*. United Nations Development Program: New York.

Chapter 15

OF TERMINATOR GENES AND DEVELOPING COUNTRIES: WHAT ARE THE IMPACTS OF APPROPRIATION TECHNOLOGIES ON TECHNOLOGICAL DIFFUSION?

Timo Goeschl and Timothy Swanson

Abstract: This paper examines the potential impacts of genetic use restriction technologies (GURTs) on various developing countries. The impact on any given country will depend on its existing biotechnology capability, the potential for developing biotechnology capability and the country's suitability for growing GURT target crops (i.e., non-hybridized species). For a large group of countries, the outcome will depend on how GURTs influence the diffusion of innovations from developed to developing countries. This is necessarily an empirical question, as GURTs will affect both the general rate of innovation and the rate of diffusion between countries. A case study of hybrid maize indicates that hybridization as a use restriction technology has slowed the overall diffusion rate of innovations to many developing countries. When GURTs are introduced it will be important to increase public research spending and to restrict other plant-related intellectual property rights so that the diffusion of innovations can continue.

1 INTRODUCTION

Terminator genes or genetic use restriction technologies (GURTs) represent a new technological advance that could help companies appropriate the monetary benefits generated by investments in plant breeding.[1] Investments in research and development (R&D) are always problematic because it is notoriously difficult to appropriate the value

[1] GURTs may come as either variety or trait based. Since the described technologies are predominantly variety based, this paper will focus only on these. The authors do not believe that the problems indicated herein would apply to trait-based GURTs.

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created by an innovation. In the case of plant breeding, this problem is multiplied because the resulting product will have built-in reproduction capabilities. This makes future purchases unnecessary, and also makes it possible for competitors to quickly and inexpensively appropriate the innovation for their own uses and profit. Partly due to these rapid diffusion rates, the agricultural R&D sector is currently a very diffuse and diverse industry, consisting of farmers, public sector institutes, private multinationals and international organizations. GURTs address the problem of appropriability, but they will also have substantial impacts on this overall R&D structure. This paper attempts to disentangle some of these various impacts, seeking, in particular, to differentiate their likely effects on developing countries.

The paper first discusses the assorted factors that will determine the impacts of GURTs on various countries. These factors are then used to classify nearly one hundred different developing countries by reference to the new technology's anticipated impact. This shows that nearly half of the developing countries will have their benefits determined by the diffusion rate that exists under the new technology. Because there is no information available about the rate of innovation diffusion under GURTs, another R&D appropriation system that has already been in place for some time, namely, hybridization, is also examined. We briefly present a case study about the ramifications of hybrid maize, considering the interrelationship between the appropriation system (hybridization) and the level of public spending. Based on this, we derive some policy implications about how to maintain a sufficient rate of innovation diffusion in spite of GURTs.

2 FACTORS THAT WILL DETERMINE THE IMPACTS OF GURTs

GURTs would be used to better appropriate the benefits derived from innovations in seed development. This could be achieved partly through biotechnologies that make future generations of seed sterile, which would require farmers to repurchase seeds each planting season. This enhances appropriability because farmers purchasing the seed once would not be able to compete with the seed company by supplying seed with those characteristics in the future (for purposes of sale or own use).[2]

[2] An alternative method for achieving this same object would be to adopt laws restricting the re-sale or re-use of commercially acquired seed. This method has been implemented in those countries that have adopted intellectual property rights (IPRs) (i.e., plant breeders' rights (PBRs) and/or patents), and strictly enforced them against their citizens. To a large extent, GURTs should be seen as a technologically supplied alternative to these systems, with the

At first glance, there is no reason to believe that enhanced appropriability harms the interests of farmers. After all, the *direct effect* of this technique will correspond only to the appropriation of the increased value of the innovations contained within the GURT seed. Farmers will continue to have the ability to purchase normally reproducing seed without the GURT seed's innovations. This option will constrain the price at which GURT seed can be marketed, limiting it to the added value of the innovation it contains. Therefore, at first sight, there is no reason to believe that farmers could be made worse off through the introduction of GURTs. Such technologies would merely add an option that did not exist previously.

However, there are also significant *indirect effects* that may result from the introduction of these technologies. For example, in the future, farmers refusing to purchase GURTs may be denied not only the single restricted use innovation (attached to a general use plant variety), but also the use of an entire series of past innovations that have never diffused into general agriculture. This potential impact on the diffusion of agricultural innovations is the most problematic characteristic of the new technology. We can gain an understanding of the significance of this problem by contrasting how agricultural innovations diffused in the past with how they are likely to diffuse in the future.

In the past, because breeders were able to use innovations in plant varieties, they diffused into general use over time even if released as protected varieties.[3] Sometimes private individuals undertook this breeding activity but many times it occurred within public institutions. In fact, publicly funded institutions (both at national and international levels) have placed substantial funding and efforts into ensuring that recent innovations are diffused throughout developing countries. These public agricultural research institutions have accomplished this by taking observed innovative characteristics and breeding them into locally used varieties.

A big difference between GURTs and the previous appropriation systems, therefore, is that GURTs capture the value of the innovative characteristics by maintaining control over the plant variety in which they are embedded. These distinctions between the "innovative characteristics"

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important difference that individual countries do not have the option under GURTs to decide to adopt the system or to determine the degree of enforcement. In this paper we examine the impact of switching from such IPR-based R&D systems to GURT-based systems.

[3] There are several important distinctions between PBR systems and GURT-based systems. First, PBR systems are limited in duration, while GURTs are not. Second, PBR systems often contain an "own use" exemption for farmers that enable their own breeding activities. Third, and most important, PBR systems merely disallow the marketing of the same plant variety in competition with its innovator; they do not disallow breeding activities making use of the new plant variety (e.g., to translocate its innovative characteristics to other plant varieties).

and the "plant variety templates" (on which they are embedded) are categorized as the "software" and the "hardware" components of modern plant breeding activities. To a significant extent in the past, even when private breeders have developed the software, much of it was quickly and inexpensively diffused throughout the developing world by incorporating it into different hardware.

The movement toward GURTs, however, may restrict the diffusion of recent innovations to developing countries. The software would become hardware-specific, and it would be entirely up to the discretion and motivation of the innovator to diffuse its innovation to all the parts of the world that could benefit. In other words, the most significant (albeit indirect) impact of this change in technology would be the potential elimination of a currently diverse R&D sector (farmers, public sector, private sector), and its replacement with a fairly homogeneous and highly concentrated private sector. It would be possible for the rate and extent of the diffusion of future innovations in agriculture to be determined solely by the originator of the initial innovation.

This creates at least two problems. First, with sufficient time and a significant number of innovations, the other currently existing suppliers of plant varieties (private and public) might be rendered commercially obsolete. This would be the case if the alternative suppliers could only acquire the characteristics at high prices, and thus were only able to supply inferior substitute varieties. Then the farmer might face a small number of suppliers of viable seed, and consequentially much higher prices for GURT seed varieties.[4] Second, if this were to happen, then the private sector might be able to effectively eliminate the public sector from all breeding activities because of the need for licenses and the restrictiveness of material exchanges. This might have negative consequences for those countries that are most dependent on public investment for their plant breeding needs.

Another problem is that commercial firms may not have sufficient private incentives to diffuse their software widely (i.e., across a diverse enough array of plant varieties). New innovations would be targeted only at those markets where there was adequate demand, and general diffusion would be prohibited in order to protect those markets. Agricultural producers on the fringes would have to farm using either the innovative characteristics embedded in poorly performing varieties or the best local varieties but without the innovative characteristics.

[4] This would be the result of a refusal to license innovations at reasonable prices to potential competitors and the maintenance of very low prices until competitors were removed from the market. Microsoft has been charged with this sort of conduct.

Using GURTs as an appropriation system is important primarily for the indirect effects that it might have on the entire system of current agricultural R&D. These indirect effects might make a tremendous difference in the diffusion rate of innovations to some developing countries. In the following sections we first attempt to segregate between the various categories of countries, and then seek to assess the extent to which the rate and direction of innovation would be slowed in those countries most affected.

3 CATEGORIES OF COUNTRIES

As the above discussion indicates, a few key factors will determine the impacts of GURTs on developing countries. The first factor is the capability of the developing country to undertake its own biotechnology R&D. If it has this capacity, then there will be little change in the rate of technological diffusion with the introduction of GURTs because these countries will be able to "reverse engineer" GURT varieties.[5] In fact, for these countries (the biotechnology capable) the impacts of GURTs are primarily positive. So, the first important question for ascertaining the impact of this new technology is: Does the subject country possess biotechnological capabilities? The second related question is: Does the country have potential to develop biotechnology capabilities in the medium run?

For countries without biotechnological capabilities, the most important question is what the impact of GURTs will be on the diffusion rate of innovations within their agriculture. To address this question, we considered an analogue in the agricultural industry. Approximately 50 years ago, the agricultural industry experienced a technological revolution with the hybridization of sexually reproducing crops such as maize. To a large extent the advent of GURTs simply extends the effects of these forms of technologies to asexually reproducing or open-pollinated crops (such as wheat and rice). The third important factor, therefore, for determining the impact of GURTs is related to the current crop portfolio: Does the subject country have a significant investment in crops that are amenable to GURTs (such as wheat and rice)?

The fourth important question is the extent to which the agronomic needs of non-capable countries will be covered by R&D in other, biotechnology

[5] The GURT system has little effect on biotechnology capable countries, precisely because they can use biotechnology to unravel and relocate the innovative characteristic. In this case, the GURT merely provides a short term advantage to the innovative breeder, possibly a head start of only two or three years in the marketing of the characteristic. The problem is greater for those countries that have both little biotechnological capacity and little investment by others interested in diffusing innovative characteristics into their local varieties.

capable countries. How quickly will the benefits from the technology diffuse to the non-biotechnology country? Again, the experience with the hybridized modern varieties is instructive because we can examine how quickly and how extensively an individual country has benefited from innovations in maize breeding conducted in other countries.

4 CRITERIA FOR CLASSIFICATION

We identified four criteria to classify countries according to the four questions posed above:

- *Biotechnology capability.* The biotechnology capability of a country is assessed by two different measures. Measure (1) looks at the stage of biotechnology development. "Capable" means that a country is presently able to produce genetically modified organisms. "Advanced" means that it is within 5 years of being able to do so, "nascent" means that a country is likely to become capable within 10 years. "Preparatory" means that a country has taken some initial steps and provided public funding to establish biotech capability. The countries named have been identified in a report by Komen and Persley (1993). Measure (2) refers to the country's share of the global area of transgenic crops, indicating its agri-biotechnological stage and experience with genetically modified organisms (GMOs). The data used have been compiled by James (1998).
- *Potential to develop biotechnology capability.* To assess the potential of a country to develop biotechnology capability, we use two different measures (measures 3 and 4). Measure (3) ranks a country in terms of its openness to foreign direct investment (FDI). It is assumed that the transfer of biotechnology will require substantial foreign investments in human and physical capital, and this measure appraises a country's probability of benefiting from the transfer of biotechnological knowledge from the developed world. Countries are ranked from 1 (very open) to 5 (closed to FDI). Because the stringency of a country's regulations is another important factor when it comes to the speed of biotechnology development and application, measure (4) ranks countries in terms of costliness and impediments to economic freedom through governmental regulation. Countries are ranked from 1 (low level of regulation) to 5 (very high level of regulation). Both rankings are based on a study by Johnson and Holmes (1998).
- *Current crop portfolio.* Measure 5 indicates the potential impact of GURTs by ranking countries according to the amount of arable land currently used for open-pollinated crops, which are likely to be early

subjects of GURTs. Countries that have either exhausted their arable land in the cultivation of crops that are available as hybrids or grow an exotic portfolio of crops achieve a low score, whereas countries growing a lot of rice, wheat and other likely GURT target species achieve a high score. The data for this measure are compiled on the basis of official international statistics (FAO, 1999).

- *Diffusion of innovations from the biotechnology capable.* To assess the likelihood that biotechnology innovations will diffuse to the subject country, we use measure 6, which is derived from the case of maize hybrid varieties. Measure 6 indicates the extent to which a given country is operating at the technological frontier in maize production, (i.e., it shows the gap between the country's yield in maize and the developed country mean yield). This is a rough indicator of a country's current ability to capture productivity rents from a crop for which the most productive varieties are technologically protected. Countries with a high gap have problems at present to fully capitalize on the best technology available. The underlying data are based on FAO (1999).

5 IMPACT GROUPS AND GURTs

Three basic assumptions are instructive in assessing GURTs' economic impacts on a given country. First, given that the country has biotechnological capability, we assume that GURTs will increase the appropriability of the value (or rents) from plant breeding activities. Second, we assume that GURTs will have positive impacts on the productivity of agriculture in those countries where (i) biotechnology capability is existent, and (ii) significant land area is dedicated to likely GURT target crops. Third, we assume that when a country is not biotechnology capable, then the impacts of GURTs will largely depend on the rate of innovation diffusion to that country (i.e., to what extent do the needs of the given country factor into the plans and objectives of the biotechnology-based plant breeding sector in other countries?). These assumptions lead to the categorization of the developing countries into five distinct groups:

- *Group A*. This group consists of countries with existent biotechnology capabilities that will produce GURT-based crops themselves. Group A is the class of countries for which GURTs are likely to have an immediate and positive impact. They will experience an immediate increase in R&D, in the appropriation of R&D rents and in the rate of agricultural productivity growth.

- *Group B.* This group includes those countries with an incipient biotech sector. This may be the result of either an already existent but immature sector or a good prospect for the development of biotechnology capacity through foreign investment and low levels of regulation. In other words, these countries have a good potential to catch up to group A. Group B is the class of countries for which GURTs are likely to have a positive impact in the medium term. They will experience a medium term increase in R&D, in the appropriation of R&D rents and in the rate of agricultural productivity growth.
- *Group C.* In this group we classify countries likely to convert their agriculture to GURT-based systems. These countries will reap the productivity benefits from the technology, although they will be unable to develop domestic biotechnology capacity for the time being. They have a built-in tendency toward GURT crops, and a moderately high rate of innovation diffusion from other countries' plant breeding sectors. Group C is the class of countries for which GURTs are likely to have an uncertain impact due to countervailing effects. They are unlikely to benefit from their own biotechnological capacities, but they have indicated that they do benefit from relatively rapid and extensive diffusion of innovations from other countries. They will probably undergo a decrease in appropriation of R&D rents but could still experience an increase in the rate of agricultural productivity growth.
- *Group D.* This group is made up of those countries that are currently highly dependent on public R&D spending and may lack the liquidity to adopt risky new technology. This means that these countries are in danger of suffering disadvantages from GURTs, particularly through a slow-down in the rate of agricultural productivity growth. Because innovations from other countries' plant breeding sectors do not necessarily confer productivity benefits, these are "slow diffusion" countries. The actual impacts will depend on the extent to which innovations diffuse from biotechnology capable countries.
- *Group E.* This group consists of those countries with a small amount of land in crops likely to be targeted by GURTs. Although these countries will not benefit from this biotechnology in any way, they will also not be in a worse position than before. Group E is the class of countries for which GURTs are likely to have little impact, positive or negative.

Table 1 classifies 98 developing countries in accordance with the indicators and criteria set forth above. It should be noted that the grouping used here is intended only for illustrative purposes. Clearly, there may be better proxies and measures of the indicators than we have discussed, and these would group developing countries differently. Table 1 indicates that the impacts of GURTs will be non-uniform and highly variable but that the variability of the impacts will nevertheless be systematic and reasonably predictable.

Table 1: Developing countries grouped according to GURT impacts

Country	Stage of biotech developm. (meas. 1)	Percent of global transg. area (meas. 2)	FDI index (meas. 3)	Regulatory environm. (meas. 4)	GURT target crops in total arable land (%) (meas. 5)	Percent yield gap in maize (meas. 6)
Group A (immediate positive impact)						
Argentina	Capable	15	2	2	64	-29
Brazil	Capable	0	3	3	45	-61
Chile	Capable	0	2	2	23	25
China	Capable	14	3	4	77	-27
India	Capable	0	4	4	60	-76
South Africa	Capable	1	2	2	8	-66
Thailand	Advanced	0	2	3	68	-51
Turkey	Advanced	0	2	3	51	-45
Group B (near term positive impact)						
Colombia	preparatory	0	2	3	46	-75
Egypt	nascent	0	3	4	100	-2
Indonesia	advanced	0	2	4	87	-63
Jordan	n.a.	0	2	3	44	-11
Kenya	preparatory	0	3	4	9	-77
Malaysia	advanced	0	3	2	36	-75
Mexico	capable	1	2	4	9	-68
Paraguay	n.a.	0	1	4	87	-66
Philippines	nascent	0	3	4	100	-77
Zimbabwe	preparatory	0	4	4	31	-85
Group C (uncertain impact, moderate diffusion)						
Algeria	n.a.	0	3	3	41	-69
Bolivia	n.a.	0	2	4	53	-54
Iran	n.a.	0	5	4	44	-14
North Korea	n.a.	0	5	5	86	-49
South Korea	n.a.	0	2	3	72	-42
Laos	n.a.	0	5	5	100	-65
Suriname	n.a.	0	3	4	95	-67
Uruguay	n.a.	0	2	3	42	-63
Vietnam	n.a.	0	4	5	100	-65

Table 1 (continued)

Country	Stage of biotech developm. (meas. 1)	Percent of global transg. area (meas. 2)	FDI index (meas. 3)	Regulatory environm. (meas. 4)	GURT target crops in total ar. land (%) (meas. 5)	Percent yield gap in maize (meas. 6)
Group D (uncertain impact, slow diffusion)						
Afghanistan	n.a.	0	n.a.	n.a.	34	-83
Bangladesh	n.a.	0	3	5	100	-85
Benin	n.a.	0	3	3	76	-82
Bhutan	n.a.	0	n.a.	n.a.	45	-88
Burkina Faso	n.a.	0	2	4	22	-80
Cambodia	n.a.	0	3	4	55	-83
Chad	n.a.	0	4	4	18	-81
Costa Rica	n.a.	0	2	3	39	-74
Ecuador	n.a.	0	2	4	50	-83
Eritrea	n.a.	0	n.a.	n.a.	61	-89
Ethiopia	n.a.	0	4	4	24	-77
Guinea	n.a.	0	3	4	67	-85
Guinea-Bissau	n.a.	0	4	5	25	-86
Guyana	n.a.	0	3	4	30	-83
Haiti	n.a.	0	4	5	32	-89
Iraq	n.a.	0	5	4	58	-77
Ivory Coast	n.a.	0	3	4	47	-88
Kuwait	n.a.	0	4	2	100	?
Lebanon	n.a.	0	3	3	20	-66
Lesotho	n.a.	0	3	4	92	-87
Madagascar	n.a.	0	4	3	52	-88
Malawi	n.a.	0	3	4	57	-75
Mali	n.a.	0	2	3	22	-76
Mongolia	n.a.	0	3	4	23	?
Morocco	n.a.	0	2	3	47	-94
Mozambique	n.a.	0	4	5	31	-87
Myanmar	n.a.	0	4	5	65	-75
Nepal	n.a.	0	4	4	100	-76
Nigeria	n.a.	0	2	4	18	-81
Pakistan	n.a.	0	2	4	70	-81
Peru	n.a.	0	2	3	20	-70
Qatar	n.a.	0	3	4	12	?
Sierra Leone	n.a.	0	3	4	71	-87
Sri Lanka	n.a.	0	3	3	99	-84
Swaziland	n.a.	0	2	3	31	-73
Syria	n.a.	0	4	4	66	-77
Tanzania	n.a.	0	3	4	100	-81

Table 1 (continued)

Country	Stage of biotech developm. (meas. 1)	Percent of global transg. area (meas. 2)	FDI index (meas. 3)	Regulatory environm. (meas. 4)	GURT target crops in total ar. land (%) (meas. 5)	Percent yield gap in maize (meas. 6)
Group D (continued; uncertain impact, slow diffusion)						
Tunisia	n.a.	0	2	3	46	?
Venezuela	n.a.	0	3	3	10	-63
Yemen	n.a.	0	4	4	20	-79
Group E (low impact)						
Angola	n.a.	0	4	5	2	-89
Belize	n.a.	0	2	3	12	-70
Botswana	n.a.	0	3	3	0	-97
Burundi	n.a.	0	4	4	6	-84
Cameroon	n.a.	0	3	4	4	-79
Congo (Zaire)	n.a.	0	5	4	12	-88
Cuba	n.a.	0	5	5	4	-82
Dom. Rep.	n.a.	0	3	4	13	-82
El Salvador	n.a.	0	1	3	15	-72
Gabon	n.a.	0	2	3	1	-75
Gambia	n.a.	0	4	4	11	-80
Ghana	n.a.	0	3	4	10	-79
Guatemala	n.a.	0	3	4	5	-72
Honduras	n.a.	0	3	4	1	-86
Libya	n.a.	0	5	5	13	-84
Mauritania	n.a.	0	3	4	7	-91
Namibia	n.a.	0	2	3	0	-89
Nicaragua	n.a.	0	2	4	4	-84
Niger	n.a.	0	4	4	1	-83
Oman	n.a.	0	4	3	4	?
Panama	n.a.	0	2	3	13	-82
Papua New G.	n.a.	0	3	4	1	?
Rwanda	n.a.	0	4	5	2	-85
Saudi Arabia	n.a.	0	4	3	11	-72
Senegal	n.a.	0	3	4	6	-86
Somalia	n.a.	0	4	5	4	-91
Sudan	n.a.	0	4	4	2	-96
Togo	n.a.	0	4	5	12	-87
Uganda	n.a.	0	2	2	8	-82
U. Arabic E.	n.a.	0	4	2	1	?
Zambia	n.a.	0	2	4	2	-78

Note: n.a. means not available.

6 THE DIFFUSION PROBLEM

Table 1 classifies 40 of the 98 developing countries belonging to group D. It is by far the most prominent group of the five different classes. For reasons explained below, this is also the group that is the most difficult to assess for the net impact of GURTs. It consists of countries that are not likely to command biotechnologies and their commercial application for the foreseeable future. This means that they will certainly be adversely affected by the shift in the share of R&D rents from farmers and consumers to plant breeders. With no significant R&D contributions to protect through GURTs, the R&D balance will move against these countries. On the other hand, with reasonable shares of land under potential GURT crops, improvements in the rate of agricultural productivity growth are possible. The problem for the countries in group D lies in slow spill-in of benefits from protected technologies as the maize yield gap indicates. It is likely that the countries in this group will face similar problems when technological protection becomes available for GURT target crops.

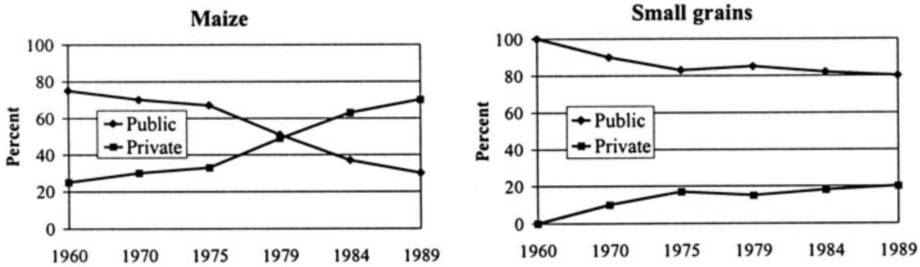
The unsatisfactory track record in catching up to productivity developments in maize shifts the focus to the problem of the diffusion of crop improvement across countries. Many countries in group D rely heavily on the trickle-down of productivity gains mediated through public plant breeding institutions and local farmer breeding (Conway and Thoenissen, 2000). The important issue is the extent to which the experience with maize can be generalized to GURTs, and this can be analyzed by looking somewhat deeper into the impacts of hybridization technologies on the character of the R&D sector. This is done by briefly discussing the results from a case study on hybrid maize.[6]

Results from the Maize Case Study

Figure 1 illustrates the share of public and private sector spending on the improvement of maize and open-pollinated small grains at the global level from 1960 to 1989. As can be seen, public sector research still prevails in the improvement of small grains. For maize, however, the availability of hybrid varieties increased private plant breeding activities and reduced the involvement of the public sector. This outcome indicates that the integration of the "software" and "hardware" of plant breeding makes the private sector more profitable while rendering the public sector infeasible. The public

[6] See Goeschl and Swanson (2000) for the complete case study on the diffusion of hybrid maize varieties.

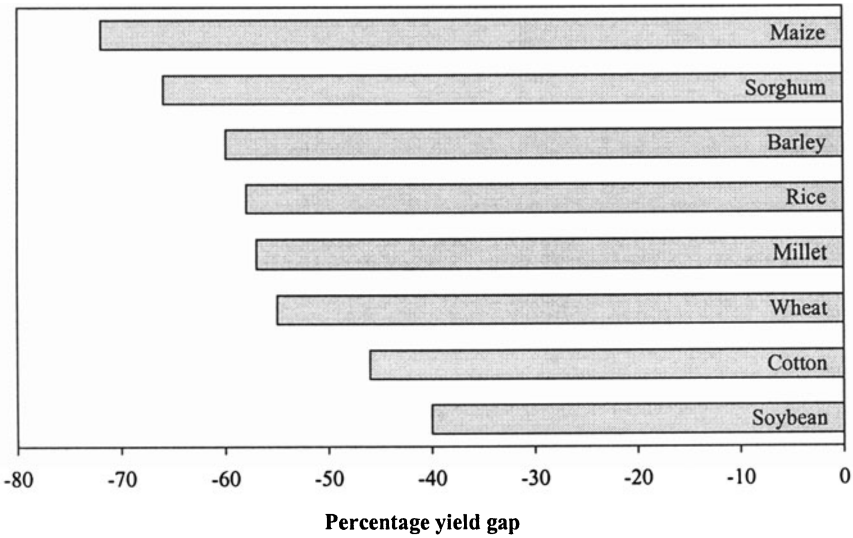
Figure 1: Share of public and private R&D spending on maize and small grains at the global level (1960-89)



Source: Based on Fuglie et al. (1996).

sector no longer offers a generally competitive alternative to the private sector's plant varieties, and so it leaves the field to the private sector. In other words, the possibility of privately appropriating R&D rents through hybridization entails to some extent a crowding out of public research.

Figure 2: Average yield gap of developing countries in comparison to developed countries



Note: The figure shows the differences in the unweighted 1999 average yields of developing and developed countries. Weighting by area harvested would lead to even significantly higher gaps. The country classification is based on Pardey et al. (1991).

Source: FAO (1999).

Clearly, the private sector is not putting the same amount of effort into diffusing its innovations throughout the developing countries. Just as clearly, the public sector is unable to continue to function in these markets, probably due to the restricted flow of materials and characteristics. The replacement of the mixed system of R&D with the private sector version has resulted in a systematic widening of productivity gaps between rich and poor countries in maize. Figure 2 illustrates this maize yield gap in comparison to open-pollinated crops.

The results from the case study on hybrid maize show what severe difficulties countries classified in group D might face with respect to GURTs. The critical factor for the countries in group D is the rate of diffusion that will exist under GURTs. The maize case study suggests that there is good reason to be concerned that the diffusion rate will slow under GURTs, since the flow of plant materials and the level of public funding are restricted. Policy alternatives must therefore be identified to avoid having the same experiences with GURTs that occurred in the maize sector.

7 THE IMPACT OF GURTs: POLICY CHOICES

Because the impact of appropriation technologies will likely depend on public policies, it is important to consider the interaction between technological and policy developments. If the public sector combines GURTs with different funding and management policies, it is possible that their impact might differ significantly from those of hybrids.

Table 2 displays the rates of innovation diffusion for three different appropriation systems under two different assumptions for public R&D spending. For example, the Table indicates that the rate of innovation diffusion in hybrid varieties is slow with low levels of public funding (as the maize case study indicates), but this is likely to increase significantly if public sector funding increases. On the other hand, the diffusion of innovations for open-pollinated varieties is currently much more rapid and extensive than it is for hybrid varieties (but also dependent on public sector expenditures). It becomes evident that agricultural R&D currently registers very different impacts on developing countries, depending on whether the variety is a hybrid one or not (cf. Srivastava et al., 1996). The critical issue for the impact of GURTs is whether these technologies will more closely follow the current example of the hybrid or the open-pollinated crop sector.

In the following, the implications of different forms of appropriation thought possible for GURTs are discussed, after defining the baseline scenario, which is the current form of IPR protection:

Table 2: Rate of innovation diffusion under different appropriation systems dependent on the level of public R&D funding

	Level of public R&D funding	
Appropriation system	Low	High
Current IPRs		
Hybrid varieties	Slow	Moderate
Open-pollinated varieties	Moderate	Fast
IPRs and GURTs	Slow	Moderate
GURTs only	Slow/moderate	Fast

- *Current IPR-based system (baseline scenario).* This is the current system, in which GURTs are not used. Legal protection through IPRs must be sought to protect R&D investment, whereby technological protection is possible for a small set of outbreeding crops through hybridization. Under this current system, IPRs remain the sole source of protection for R&D inputs into improvements of open-pollinated crops.
- *Combined use of GURTs and IPRs.* This scenario is probable, since it does not require any changes in the existing legal structure. The situation would closely resemble the one that presents itself currently with combined legal protection and technological protection through the use of hybrid cultivars. The introduction of GURTs would extend the feasibility of these combined regimes (beyond outbreeding crops). It will likely restrict the vast majority of agricultural R&D to the private sector and slow the diffusion of innovation to developing countries in group D.
- *GURTs only, public sector policies directed to diffusion.* It is possible for a combination of public sector policies to make the advent of GURTs a win-win situation. This would be the case if public policies were directed to speed the diffusion of private sector innovations (protected only by GURTs) throughout general agriculture. This would occur by means of enhanced public investment in R&D for the express purpose of reverse engineering the GURT-protected characteristics, with the object of translocating them into local varieties for developing countries. GURT-based protection probably would be adequate to maintain appropriability of a new plant variety for about three years, and so it would afford some protection to the innovators. The removal of other (IPR-based) constraints on diffusion would aid the rapid extension of these innovations to developing countries.

8 CONCLUSION

GURTs are positioned to become an additional technological solution to the problem of rent appropriation. They extend the solution concept of hybridization to open-pollinated crop species. This suggests that the rates of diffusion currently observed for hybrids will be extended to those crops that are currently protected only through IPRs. Such a scenario implies a significant decline in the rate of innovation diffusion across agriculture. In particular, it suggests a problem for those developing countries identified previously as dependent on the public sector for the diffusion of agricultural innovations.

The only real alternative is to meet this technological advance with public policies that address its deficiencies. Such public policies will aid the diffusion of innovations from the private sector to the public sector, and then on to those developing countries with little biotechnological capability. In short, the public sector must manage diffusion impediments through funding directed to the reverse engineering of GURT-protected innovations and to the diffusion of these characteristics into general agriculture. It must also make clear that GURTs will function well as an alternative to IPR-based protection systems, not as a complement to them.

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REFERENCES

Conway, G., and G. Thoenissen (2000): Biotechnology, Food and Nutrition. *Nature*, Millenium Supplement, forthcoming.

FAO (1999): FAOSTAT Online Database; Production Statistics. Food and Agriculture Organization of the United Nations, Rome.

Fuglie, K., N. Ballenger, K. Day, C. Klotz, M. Ollinger, J. Reilly, U. Vasavada, and J. Yee (1996): Agricultural Research and Development: Public and Private

Investments Under Alternative Markets and Institutions. AER-735, Economic Research Service, United States Department of Agriculture, Washington, D.C.

Goeschl, T., and T. Swanson (2000): The Diffusion of Innovations: The Example of Hybrid Plant Varieties. Mimeo., Department of Economics, University College, London.

James, C. (1998): Global Review of Commercialized Transgenic Crops: 1998. ISAAA Briefs, No. 8. International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

Johnson, B., and K. Holmes (1998): *The 1999 Index of Economic Freedom*. Dow Jones and Co., Heritage Foundation, New York.

Komen, J., and G.J. Persley (1993): Agricultural Biotechnology in Developing Countries: A Cross-Country Review. ISNAR Research Report, No. 2, International Service for National Agricultural Research, The Hague.

Pardey, P, J. Roseboom, and J.R. Anderson. (eds.) (1991): *Agricultural Research Policy; International Quantitative Perspectives*. Cambridge University Press, Cambridge.

Srivastava, J, N. Smith, and D. Forno (1996): Biodiversity and Agriculture. Implications for Conservation and Development. Technical Paper, No. 321, The World Bank, Washington D.C.

PART IV

INTELLECTUAL PROPERTY RIGHTS

OVERVIEW

Per Pinstrup-Andersen

This part of the book examines the increasing complexities of strengthened intellectual property rights (IPRs) in the area of agricultural biotechnology, in particular the repercussions for developing countries' access to biotechnological innovations. Recent developments related to IPRs for living organisms have created both opportunities and threats in the area of agricultural research for developing countries. While the possibility to patent new crop varieties and other research outputs aimed at commercialization allows research institutions to capture at least some of the benefits of their innovations, it also threatens the freedom to operate for other researchers, including the public-sector agricultural research systems. The threat originates from the ability to obtain exclusive rights not only to research outputs for commercialization but also for research procedures, gene sequences and other components of the research process itself. To perform its function, the public-sector agricultural research system must now obtain permission to use such intermediate research processes from various patent-holders. Frequently, developing a crop variety with new desirable traits utilizes twenty to thirty patented processes and research components, the owners of which would have to agree to the commercialization of the particular variety. When one or more such patent-holders refuse to give permission at a reasonable cost, the final product cannot be legally commercialized and research investments may be lost. In other cases, the

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payments to the holders of the exclusive rights may exceed the expected value of the final product.

Adjustments in current patent legislation might be needed to assure a reasonable degree of freedom to operate for public-sector agricultural research systems. This will help ensure that the technology needed by small farmers and poor consumers in developing countries is developed. Such technology has very large social benefits, but it may be very difficult for any research agency to capture enough of those benefits to warrant research on purely commercial grounds. Therefore, public-sector investments in such research will continue to be needed.

The three papers included here approach IPR issues from different angles. *Peter Phillips* and *Derek Stovin* give a general introduction to the economics of IPRs in the agricultural biotechnology sector. In the last 25 years, the legal protection of innovations in biological research has expanded private-sector investment. Today, private life-science and biotechnology companies are the major patent-holders in agricultural research. But although strong IPRs encourage private research, the high transaction costs associated with licensing agreements could obstruct follow-up research and innovation diffusion.

Andrew Beadle discusses IPR issues in developing countries from a private-sector perspective. He argues that the lack of intellectual property protection is one of the main reasons for the poorly developed private breeding sector in many developing countries and for the limited research interest of foreign companies. He concludes that it is in the long-term economic self-interest of developing countries to protect the intellectual property of all nations, which is also required by the Trade-Related Aspects of Intellectual Property Rights (TRIPs) Agreement. In the short and medium term, however, Beadle also sees a more supportive role for companies from the developed world. Through targeted transfers of certain technologies and know-how to local agencies in the South, private companies can contribute to national capacity building in developing countries, which could facilitate commercial projects in the future.

Brian Wright discusses IPR issues for international research collaborations in a broader context. He argues that the centers of the Consultative Group on International Agricultural Research (CGIAR), whose mandate is the provision of appropriate agricultural technologies to the poor, are placed at a particular disadvantage due to their lack of IPR resources and clear policies. Wright presents several possible strategies for overcoming some of these difficulties. He notes that identifying institutional solutions and implementing public-private sector partnerships and technology transfers on a larger scale remains a challenging task.

These three papers suggest that there is still a great deal of uncertainty about what an appropriate IPR framework should look like. The application for patents is country specific, and most existing patents related to agricultural research are held in the industrialized countries. Thus, to the extent that patents are not taken out in a particular developing country, that country's national agricultural research system is free to use the research processes and traits in further research and adaptation. Farmers in those countries are free to use commercialized improved seed even though it may be patented in other countries. The country, however, will not be able to export commodities produced by such seeds to countries where patents are in effect. Still, private-sector corporations are likely to take out patents only in countries where they expect a sufficiently large commercial demand for the patented product. Similarly, since patenting is a costly affair, patent-holders of specific aspects of the research process may limit their applications of patents to a few countries where they can obtain significant economic gains.

Although all members of the World Trade Organization (WTO) must develop acceptable IPR regimes, many of the poorest and smallest developing countries may not be greatly affected by the rapid increase in patenting of agricultural research processes and outputs. Patent-holders will likely not take out patents in those countries. Thus, an implicit market segmentation is developing where countries and agricultural commodities with little interest to the private sector may be free to use novel research processes and traits patented elsewhere.

Ideally, agreements should be reached between public-sector agricultural research institutions in developing countries and the major patent-holders (i.e., the big life-science corporations as well as a large number of small biotech companies). Such agreements would recognize this market segmentation and make modern biotechnology available for further research and adaptation to benefit poor farmers and poor consumers in developing countries. Such an agreement should provide free access to appropriate technology for farmers in developing countries. In other words, such innovations would be public goods in those segmented markets. The CGIAR would be an appropriate international organization to facilitate such agreements. At the same time, it should continue to pursue collaborative research with developing-country agricultural research systems to develop the most appropriate public goods research for the benefit of the poor.

Chapter 16

THE ECONOMICS OF INTELLECTUAL PROPERTY RIGHTS IN THE AGRICULTURAL BIOTECHNOLOGY SECTOR

Peter W.B. Phillips and Derek Stovin

Abstract: Economic theory highlights the critical importance of excludability in encouraging private research in the agri-food sector. Without it, private research will languish and social welfare could suffer. Since 1973, governments around the world have recognized this and strengthened the legal protection for biotechnology processes and products (e.g., patents, plant breeders' rights and trademarks). These new rights have been integrated into a complex system of public and private protection for intellectual property. Consequently, this new policy spurred significant private investment in biotechnology, but a number of policy concerns have arisen: levels of intellectual property protection may be too high, thereby choking off spillovers, follow-on innovations and diffusion. This has raised questions about the optimal public role in regulating, conducting and supporting research and trade in biotechnology. Ultimately, developing countries are faced with little choice but to accept the existence of private property rights and use them for their own best interests.

1 INTRODUCTION

Approximately 40 percent of the world's market economy is now based upon biological products and processes (Gadbow and Richards, 1990). Although biological knowledge has been part of the economy for centuries,[1] since 1973 modern Mendelian plant breeding, in particular, has been increasingly influenced and driven by new molecular biology techniques.

[1] One of the oldest large-scale applications of biotechnology by industrial societies was the cleansing of wastewater through microbial degradation in the nineteenth century (OECD, 1999).

M. Qaim et al. (eds.),
Agricultural Biotechnology in Developing Countries: Towards Optimizing the Benefits for the Poor, 259–280.

Knowledge and technologies flowing from innovations in basic biology – usually categorized as "biotechnologies" – have profoundly influenced the development of the agricultural economy and will continue to be important for the industry's future development.

New or strengthened intellectual property rights (IPRs) regimes for biotechnologies have been one of the key spurs to this transformation. They have fundamentally influenced the structure and location of global agricultural activities. In this paper we examine the characteristics, role and use of IPR regimes in the global agri-food sector and identify a number of policy implications.

2 BACKGROUND OF PROPERTY AND PROPERTY RIGHTS

Most economists from Adam Smith (1776) to today begin any discussion about development with the premise that an "invisible hand" of self-interested actions of individuals and firms in the marketplace can, under strict conditions, provide an optimal level of consumption, savings and investment. Three necessary conditions for optimal development are the existence of complete information, perfectly competitive markets and no barriers to entry or exit. Over the long run, however, development also requires rising productivity growth, which flows from investment in the search for innovation. Joseph Schumpeter (1954) has noted that perfect markets with free flows of information are inimical to innovation. If a firm invests to create an innovation under these conditions, any resulting benefits would be bid away by new entrants to the market, thereby making it impossible for innovators to recoup their investments. A perfectly competitive market economy would suffer a public goods market failure due to inadequate investment in innovation. Schumpeter points out that sustained innovation requires private, exclusive-use property rights to innovations that act as incentives to investment. A number of recent experiences in the transitional economies of Eastern Europe and in the research based agri-food sector have reconfirmed the importance of private property rights for development today (Alston et al., 1998a).

Property rights are social constructs that confer exclusive rights to a specific individual to use a specific product or process. In the first instance, common law has accepted and confirmed that individuals have the right to the fruits of their labor. Society has strengthened these rights by granting innovators exclusive rights to their innovations as an incentive to private investment and to encourage full disclosure. Nevertheless, these use-rights are seldom absolute. Most societies require that any owner's use of any product or process be constrained when it infringes upon another individual's rights (following Locke, 1690), and use-rights are often further constrained by society's ability to remove the exclusive use provision for the "social good". Precedents for this removal include the expropriation of land for infrastructure building and the seizure of goods allegedly obtained through illicit means. Furthermore, after the innovation is forthcoming, society would usually benefit most from unrestricted access to the innovation to improve the state of the art. As a result, intellectual property regimes require full disclosure of the innovation so that follow-on research and development (R&D) can be facilitated. At the operational level these exclusive use-rights are further limited by the definition of the scope, duration and provision that the innovation must be "worked" to be maintained.

There are actually multiple types of property. Historically, the focus has been on physical goods, but interest has shifted recently to "intellectual property", which refers to the processes or recipes for putting things together. Contrary to popular belief, IPRs are not substantially different from traditional property rights. IPRs, like traditional property rights, confer exclusive use-rights upon the individual who develops a specific innovation. Confusion abounds, though, because the innovations vary in one fundamental way. Traditional property rights usually refer to innovations that are embodied in some physical object, whereas IPRs most often refer to innovations that are ideas and, therefore, disembodied.

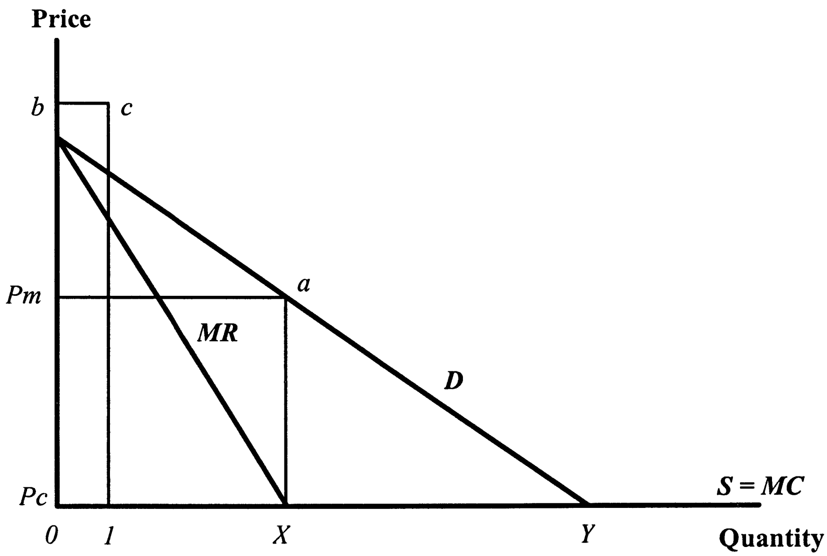
The fundamental difference between embodied and disembodied innovations is how they are used. Romer (1995) uses the examples of computers. A physical object, such as a computer, is characterized as a rival good because only one person is able to use it at any given time. Furthermore, the marginal cost of producing an additional computer is significant. It is, therefore, quite easy for the owner of the associated property right to exclude others from using it. But a disembodied item, such as the knowledge involved in a computer program, is characterized as a non-rival innovation because more than one person can use it at the same time without affecting the use of the others. As non-rival innovations are often disembodied (e.g., they are simply ideas) or they are embodied in easily and cheaply reproduced media (such as on a computer disc or in open-pollinated germplasm), they are easily widely disseminated. Public and private property rights systems have been used to try to control the reproduction and use of both types of innovation so that innovators can realize a return on their investments. Given the rival nature of most traditional innovations, traditional property rights tend to work reasonably effectively. The difficulty comes with these non-rival innovations, where it is both difficult and expensive to monitor and enforce the exclusive use-right. Establishing IPRs in law is one possible way to reduce these transaction costs.[2]

3 THE ECONOMICS OF IPRs

The excludability trait of an innovation is of preeminent importance; without it, private agents cannot recoup their investments. Exclusion of a disembodied item is difficult because, once the innovator invests in a new idea, that knowledge can often be transferred between individuals at virtually no cost. In economics terms, the marginal cost of producing more than one unit of a new idea is zero, or approximately zero, which translates into a low, flat supply curve.

Figure 1 illustrates the economics of the situation where the marginal cost of producing the innovation is zero. In this case, the supply curve is the stepped curve marked by the horizontal line between *b* and *c* and the horizontal axis from *1* to *Y* and beyond (in other words, the first unit costs

Figure 1: The economics of firm-level investment decisions

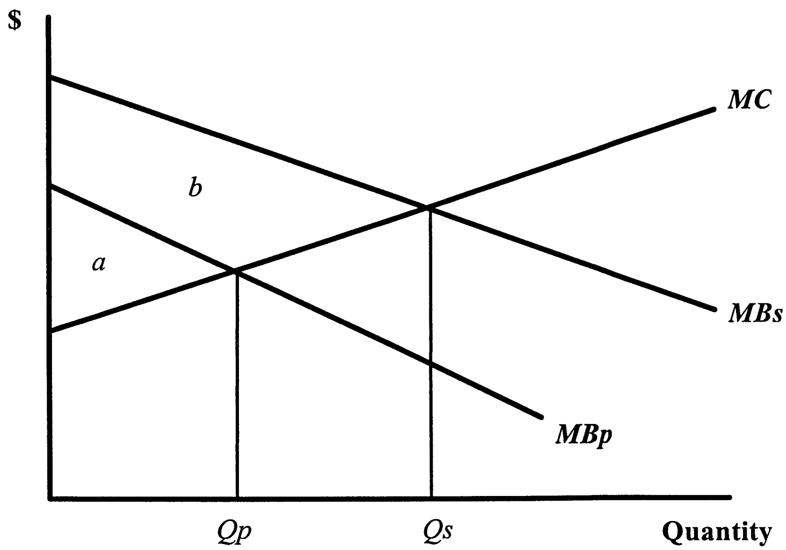


[2] Many individuals will not willingly break the law, which makes monitoring and enforcement unnecessary in many situations. It is not clear a priori whether the benefits from an IPR regime offset the legal enforcement costs incurred in the remaining situations. A public good market failure still remains for those situations where the expected legal costs exceed the expected private benefit from an innovation investment.

0bc1 to produce and then it is costless to replicate). Assume the innovator faces a downward sloping demand curve (*D*) for the innovation (a normal situation). To justify investment in the innovation, the innovator needs to expect to receive a price higher than the marginal cost (*MC*) (which equals zero). If the market is perfectly competitive, with full distribution of information and free entry, the price will be bid tangentially close to the marginal cost (which is zero) and *Y* units of the product will be produced and sold. In that case it would not be economically justifiable for anyone to invest in search of that innovation, as the innovator could not recover the investment. The downside of this is that innovation would cease and productivity stagnate. From an economy-wide perspective, society would lose significantly.

As illustrated in Figure 2, if firms cannot expect to appropriate a sufficient portion of the returns of their investments, they do not innovate optimally and a "public good" market failure exists. With incomplete or insufficient property rights, the private marginal benefit (*MBp*) that can be captured from the market place is less than the public or social benefit (*MBs*) of the research. Profit maximizing private firms will equate the marginal cost (*MC*) of doing research with the private marginal benefit of the research and produce a research quantity of *Qp*. At this amount, the social marginal benefit of research is far greater than the marginal cost of doing research.

Figure 2: Private investment with incomplete property rights



Economists point to the high rate of return on R&D in the agri-food sector as an indication of this situation (Alston et al., 1998b). The total welfare gain for producers and consumers in this case is only the area bounded by the vertical axis and the *MC* and *MBp* lines (area *a*). In this case, the marketplace fails to produce the socially optimal amount of research (*Qs)*, where the marginal cost of research is equal to the marginal social benefit. This causes economy-wide under-investment in research activities and lower than optimal welfare (i.e., by the area *b*). The traditional response has been for the public sector to undertake research directly in such situations, shifting the quantity of research undertaken outwards towards *Qs*, in an effort to create some of the potential additional benefits represented by area *b*.

More recently, governments have extended private property rights in an effort to close the gap. If effective private property rights for otherwise non-excludable innovations are possible, then innovators would be able to act as monopolists. As illustrated in Figure 1, the monopolist innovator would make production decisions based on the marginal revenue curve (*MR*), which lies below and to the left of the demand curve (*D*). As a result, the innovator would restrain supply to where the marginal revenue curve equals the marginal cost curve (the horizontal axis at point *X*) and price off the demand curve at *Pm*. The innovator would then earn revenues equal to the area *0PmaX*, which in this example is greater than the cost of the innovation. Therefore, under an IPR regime that provides an opportunity for monopoly pricing, individual firms should be willing to undertake significant further investment in innovation that would create much of the potential social welfare identified by area *b* in Figure 2. When a property right expires, competition would eliminate the ability to use the monopolist's marginal revenue. At expiration, *Y* quantity would be produced at a price approaching zero, and society would reap the innovation's full benefits. Similarly, if a follow-on innovation appears, the demand curve would shift in and reduce both the private and social benefits of the earlier innovation.

4 TYPES OF INTELLECTUAL PROPERTY AND RELATED PROTECTIONS

For agriculture, there are two key stages where intellectual property protection is both afforded and used. At the R&D stage, all firms actively protect their knowledge and innovations. Equally important, however, is the commercialization stage. The best protections at the R&D stage are strategically important, but they have limited value if innovators are not also able to extract from the market at least part of the value added by their innovations. This section discusses both stages of development and commercialization.

Much of the economic analysis of the R&D stage focuses almost exclusively on patents as the preferred means of protecting intellectual property. In practice, however, there exists a wide variety of commercial and legal strategies used by innovators to protect their research innovations. The structure and use of these mechanisms depend on the characteristics of the intellectual property itself. Malecki (1997) provides a useful way of categorizing the types of intellectual property that innovators create and use. He identified four distinct types of knowledge: know-why, know-what, know-how and know-who (Table 1). Each knowledge type has specific features that influence the choice of property protection pursued. Actors in the R&D community have adopted different strategies to protect and exploit each of these different types of knowledge.

"Know-why" refers to the scientific knowledge of the principles and laws of nature, which in the case of agriculture and plant breeding relates largely to the science of plant physiology, plant molecular biology, theoretical and applied genetics and biochemistry (including genomics). Little of the research related to these areas is undertaken in the private sector, because it often has little commercial application or, where it does, the lag between discovery and commercialization is so long and unpredictable that few firms would have any reasonable expectation of profit from such research. As a result, the vast majority of this knowledge is generated in universities and research labs (Phillips, forthcoming). For the most part, academics, public research institutions and those private companies with activity in this area choose not to exercise their IPRs for immediate monetary gain. Instead, they tend to publish the results of their research in academic journals, which

Table 1: Classification of types of knowledge

Knowledge type	Degree of codification	Produced by	Extent of disclosure
Know-why	Completely codified	Universities and public labs	Fully disclosed and published in scientific papers
Know-what	Completely codified	Universities, public labs and private companies	Fully disclosed in patents
Know-how	Not codified	Hands on in labs	Tacit, limited dispersion
Know-who	Not codified	Exists within firms or research communities	Tacit, limited to community

Source: Adapted from Malecki (1997).

usually effectively precludes future efforts to protect the resulting intellectual property through patents or plant breeders' rights. As such, publication effectively grants the author rights to citation by subsequent researchers (a key currency of academics and many public researchers) but allows the economic benefits of the innovation to become public property (i.e., non-rival, non-excluded knowledge).

"Know-what" refers to knowledge about facts and techniques. For plant breeding, this includes the specific steps involved in key transformation processes, the gene constructs and parts of the genome. By its very nature, this type of knowledge can often be codified and thereby acquire the properties of a commodity. Accordingly, this knowledge is often the target for private investment. In practice, both private companies and public laboratories develop this type of knowledge. For the most part, know-what knowledge is protected by a wide range of *de jure* and *de facto* IPR strategies. Since 1973, virtually all of the main technologies required to genetically manipulate a plant or animal have been patented in one or more of the key research countries (see Table 2 for examples of the canola breeding industry). Meanwhile, as discussed below, many other complementary strategies have been pursued.

There are two other types of knowledge that are increasingly important in the application of biotechnology. "Know-how" refers to the skills or capacity to perform a given activity. In plant breeding, this involves the ability of scientists to combine effectively the know-why and know-what knowledge to develop new plant varieties. This capacity is often learned by doing, which makes it more difficult to transfer to others and, hence, more difficult to codify. Marketing these innovations also takes a certain skill and expertise that is not codifiable but ought to be viewed as know-how knowledge.

"Know-who", which involves information about who knows what and who knows how to do what (OECD, 1996), is an often unacknowledged but vital part of any research effort. As the breadth of knowledge required to transform plants expands (involving multiple highly specialized disciplines), it is increasingly necessary to collaborate in order to access the types of knowledge needed to compete in developing new biotechnology products. Know-who knowledge is seldom codified but often accumulates within an organization. At times, it also accumulates within communities where there is a critical mass of public and private entities that engage in the same type of research and exchange technologies, germplasm and staff. Although it is often difficult to protect the intellectual property that results from these efforts, some enterprises do avail themselves of some protection. Many researchers – either voluntarily or under non-disclosure provisions in contracts with either their employer or funding partners – keep secret any

Table 2: IPR regimes related to canola breeding processes

Technology category and key technologies	IPR regime
Genomic information: maps, etc.	None; public domain; on internet
Germplasm in public and private gene collections	Restricted access only for private collections
Aliel specific amplification technologies such as SCARs, SRSLOs and micro-satellites	100 percent private patent
RDNA strands/genes for herbicide tolerance, antifungal proteins, nutritional attributes, pharmaceutical compounds, etc.	100 percent private patents
Transformation technologies such as agrobacterium, biolistics and mutagenesis	100 percent private patents except mutagenesis
Constitutive growth promoters to express genes for herbicide tolerance, disease resistance, drought tolerance, salt resistance, etc., into all cells of a plant	100 percent private patents
Tissue specific growth promoters for pod/shatter control, floral morphology, nutritional traits, etc.	100 percent public and private patents
Hybrid technologies, including In-Vigor, CMS System, Ogura CMS Systems and Bolima	All patented except Bolima, which is in the public domain
Traditional breeding technologies such as backcrossing, half seed process, double haploid process, gas liquid chromatography, shuttling and computer assisted breeding	Most in public domain; some trade secrets and potential for copyrights on computer programs

Sources: Personal communications with canola researchers and patent searches.

new innovation that might have commercial value. Through these means companies can often keep know-how and know-who from becoming one of Marshall's (1890) "mysteries in the air". Furthermore, many companies collaborate only with enterprises that have equal or greater risk of exposure for non-patentable proprietary knowledge, which creates reciprocal risk levels of premature disclosure.

Given the extent of vertical integration in the agricultural biotechnology industry, most of the research enterprises involved look downstream to farmers and the consumer market for their returns – they do not generally expect to recover their investments by selling their innovations directly. Several legal and strategic opportunities can assist firms in exploiting their innovations. Over the past 60 years, most developed countries have established plant breeders' rules, which grant plant variety protection for 15-20 years to new plant varieties. In 1978, those rights were codified in the international Union for the Protection of New Varieties of Plants (UPOV) agreement, which now has 38 signatories (UPOV, 1999). With the World Trade Organization (WTO) IPR trade agreement of 1995, all 139 WTO members are now required to develop equivalent protection. In addition, many countries have seed registration acts, which grant breeders exclusive use-rights to variety names. Some breeders have also used trademark laws to reserve commercial names for proprietary products (e.g., Liberty-link™, Roundup Ready™, Laurical™) so that they can differentiate the product and make it more difficult for others to copy their innovations and compete in the marketplace.

Even though the new IPR legal protections go a long way towards enabling commercial firms to control the use of their intellectual property, all firms additionally use one or more of the other available, non-legal mechanisms (see Table 3). Given that know-who and know-how tend to be found within firms or larger geographic clusters of research, there is a strong tendency for research communities to produce competitive, like-types of innovation that relate to specific climates, soil characteristics, microbiologies and industrial structures.

In the canola sector, for instance, some varieties can only be used in the Canadian climate (certain pests or microbes limit or curtail production in other areas), while many of the new genetically-altered varieties require a certain scale of production (e.g., large total acreage or average field size) or complementary investments (e.g., mechanized seeding, spraying, and harvest equipment). As a result, some of the Canadian canola research products cannot be transferred elsewhere. Thus, excludability between geographic jurisdictions is one strategy. Some firms have chosen to protect their intellectual property by creating products with genetic attributes that act more fully to exclude the use of the innovation. For instance, herbicide-tolerant canola varieties require the use of a specific herbicide in order to be useful (e.g., Roundup Ready and Liberty-link crops). Similarly, many of the output traits bred into crops (e.g., laurical canola bred by Calgene) have particular characteristics that require specialized processing and marketing chains in order to be exploited, which limits the opportunities for imitators. Many of the companies with such technologies also use production input contracts to control unauthorized follow-on use of their innovations (e.g., Monsanto's technology use agreements). Similarly, companies commercializing input and output traits also often rely on contracts with producers to maintain control over their innovations. In 1997, an estimated 38 percent of the canola acreage in Canada was planted under production contracts. Finally, the development of new hybrid systems for many crops has also given private firms a greater ability to capture the value of their innovations, since bin runs of progeny of F1 seed do not produce well. The corn seed trade is already virtually 100 percent hybrid. Canola hybrids were introduced in 1989 (by 1997 hybrid and synthetic varieties commanded 15 percent of Canada's market share) and a wheat hybrid system is currently in development.

Table 3: IPR regimes for canola varieties (1990-97)

Reference: 96 varieties registered in 1990-96	Varieties (number)	Varieties (percent)	Market share in 1997 [b] (percent)
Proprietary complementary technologies (e.g. herbicide-tolerant (HT) varieties)	4	4	35
Identity preserving production contracts for novel traits	10	10	<5
Hybrids/synthetics	17	18	15
Plant breeders' rights (PBRs) [a]	36	37	70
No identifiable regime	29	n.a.	n.a.

a. Companies apply for PBRs for virtually all new varieties but let applications for commercially unsuccessful varieties lapse; the 36 varieties with PBRs are those that were awarded rights before the 1997 crop year.
b. The numbers add to more than 100 percent because many varieties are protected by multiple regimes.

Sources: Canola Council of Canada and authors' calculations.

A recent analysis of the canola research and seed trade in Canada (Phillips and Khachatourians, forthcoming) revealed a complex web of *de jure* and *de facto* strategies being used to protect and assist firms in exploiting the economic potential of innovations. At the research stage, a small group of private companies now dominates the ownership and use of technologies for the breeding of new crops. Patents, trade secrets or trademarks protect virtually every step of the research process. Although many of the technologies were developed by public universities or were originally commercialized by entrepreneurial startup companies, invariably the patents have been assumed and the technologies commercialized by the larger agro-chemical, life-science companies. The public sector, in Canada and elsewhere, has been largely absent from the key areas of know-what knowledge required to transform canola. Downstream from the research business, the life-science companies have either vertically integrated their operations or developed strategic alliances with other input providers and seed merchants so that they can manage their innovations. As a result, most companies now protect their investments using a variety of mechanisms and, in most cases, use two or more protective measures per variety. In short, IPRs are interwoven into the entire agri-food supply chain, from basic research up to the final consumer product.

5 POLICY IMPLICATIONS OF IPRs IN THE AGRI-FOOD SECTOR

A number of issues arise from the recent extension of IPRs in the agri-food sector. A key, often-overlooked issue is the determination of the appropriate or optimal structure of IPR systems. A closely related question is how public research activities should accommodate increased private research efforts. In addition, IPRs have significant implications for locating research, industrial structure, distribution of returns, adoption, diffusion and trade flows.

5.1 The Optimal Structure of Intellectual Property Protection

Most economists believe that IPRs are an appropriate institutional response to overcome the public good market failure that otherwise exists. But for private research, there is significant debate about exactly what structure is appropriate for agri-food patents. Given that IPRs attempt to balance private incentives with the public good, there are no absolute answers. A number of factors are worthy of consideration.

- First, the time period for which exclusivity is granted goes a long way in determining the incentive actually being provided to innovators. The longer the period, the greater the potential benefit. Of course, if follow-on innovations are possible, then the legal limit may not be the effective limit, because the private benefit from innovation diminishes with competition. Furthermore, the net present value of revenues 15-20 years from now is worth significantly less than the net present value of returns in the first few years of an innovation.
- Second, the scope of protection offered also matters. Innovations often have multiple potential uses, many of which are not known until years after the innovation is initially commercialized. If the IPR system provides protection for wide uses, even if poorly understood and anticipated, then the expected value of the innovation increases. Recently, many patents have been challenged for having too wide a scope. In some cases, the claims being made are for anticipated applications and are not reproducible using the current art.
- Third, the limits on the use of any IPR are important. Most systems state that the property holders must work their claim or lose their exclusive rights. The length of time allowed before their claim lapses is crucial. Additionally, almost all legal IPR regimes provide for the state to buy-out existing property rights when it is in the public interest. Sometimes

this involves a transfer of funds from the public sector to the claim holder; at other times it simply involves compulsory licensing with royalties from other uses.

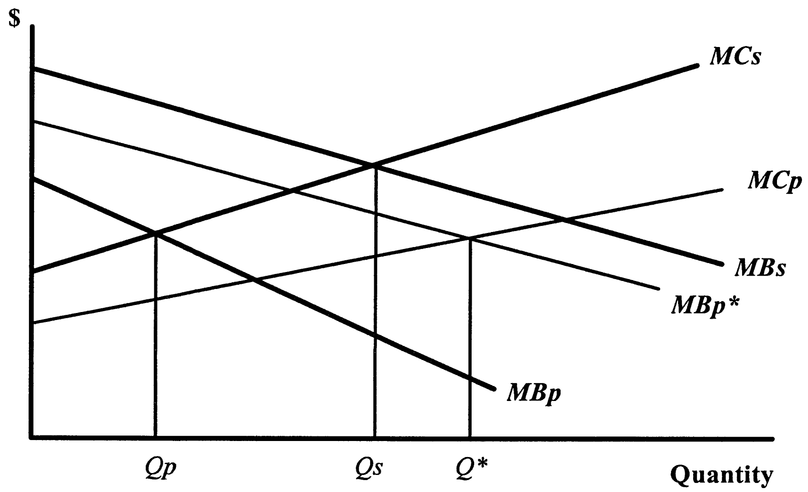
These issues, while generally important, have so far not been vital for the seed trade because the effective economic lifespan of each new variety is shrinking. In Canada, for instance, the average life of any new canola variety in the late 1990s is approximately three years, down from more than 13 years in the 1960s. A greater concern is the operation of IPRs for germplasm and genes. While there appear to be competing biotechnology transformation systems for most key crops, there is a legitimate concern about reduced competition arising from protected germplasm and genes. In many cases germplasm and genes are unique, and IPRs for these could create effective blocks to follow-on innovation.

5.2 The Appropriate Role for Public Research

The arrival of new, privately enforceable property rights requires the public sector to re-examine its role in agricultural research. There are indications that some public research support is earning low social returns and that other potentially higher return activities are under-funded. The new, privately enforceable property rights are often in addition to existing government subsidies for private programs or directly provided by public research programs. In terms of the market, the establishment of enforceable property rights moves the private marginal benefit (market demand) curve toward the social demand curve, as illustrated in Figure 3 (e.g., from MBp to MBp^*).

If the government continues to subsidize private research – either by providing free basic research or through matching research grants – then the private marginal cost curve would fall below the social marginal cost curve ($MCp < MCs$). In the case illustrated in Figure 3, the combination of private rights and public support yields excessive research (e.g., $Q^* > Qs$), with the result that more resources are expended on this activity than is socially optimal. Although this may seem unlikely, there is evidence in the global canola sector that this may be happening. Gray et al. (1999) estimate that the internal rate of return on capital invested in canola in recent years has dropped to between 4 and 7 percent, which is less than the cost of capital. That study concluded that the government decision in the 1980s to direct resources to support proprietary research, in addition to extending property rights, has overcompensated for the public good market failure.

Figure 3: Private investment with property rights and government support



Phillips (forthcoming) asserts that the shift in public support to private efforts to develop new know-what knowledge and commercial varieties in the canola sector was at the expense of public investment in the other types of knowledge research. Public output of know-why knowledge has particularly suffered during this period. This suggests that public funds currently devoted to supporting private activity could yield a higher social benefit if redirected towards other research activities. As discussed earlier, creating know-why knowledge and know-how and know-who capacity are critical elements in biotechnology research. Except in limited circumstances, there is little likelihood that the private sector alone will provide the socially optimal output. With private property rights, the public effort should be refocused on those vital public goods that cannot be produced by others.

5.3 IPRs and "Freedom to Operate"

The creation of private IPRs for agri-food innovations has opened the system to substantial private involvement in the past 20 years. One of the most pressing issues for many companies is the "freedom to operate" in a world of overlapping and interwoven claims to intellectual property. Both *de jure* (patents, plant breeders' rights, trademarks and trade secrets) and *de facto* (e.g., protected through contracts or via technical barriers such as hybrids) property rights create potential difficulties for the adoption and diffusion of innovations. The evolution of private IPRs in the agri-food sector in Canada and abroad has fundamentally altered the capacity to develop and commercialize new technology-based agri-food products or services. The development process is now often highly complex, since developers require access to germplasm and up to 15-30 different proprietary technologies to develop a single product. Even in the absence of opportunistic behavior by firms, the logistics of assembling access and licenses to all these elements is a problem by itself. For example, there are 81 institutions (59 private companies and 22 public institutes) holding 385 patents related to the *Bacillus thuringiensis* (*Bt*) gene and its use (US Patent and Trademark Office, 1999). Markets for intellectual property are just beginning to emerge: search costs are high, negotiations for licensing are extremely protracted and expensive, and enforcing rights through contracts or the courts is prohibitively expensive. For those reasons, governments are concerned about the privatization of the key technologies. The larger companies have for the most part resolved their operational difficulties through extensive cross-licensing agreements. In contrast, those companies that lack proprietary technologies to cross-license and those public and private research programs that target minor crops or minor agronomic traits tend to get priced out of the market for new proprietary technologies. More importantly, however, in many cases the strategies that companies use to protect their rights have created real barriers to entry for new firms as well as impediments for both public and private research. Anecdotal evidence suggests that some companies are strategically exploiting their core proprietary technologies. If a proposed use of a proprietary technology would create a non-competitive product, IPR holders often ask for a significant royalty or share of equity in exchange for access. If the proposed use would create a competing product, access is often denied or the project is taken over by the IPR holder. All of these situations have caused governments to question whether the anti-competitive features of IPRs need to be limited, which could be pursued through revisions to the patent rules or through anti-trust actions.

5.4 IPRs and Economic Growth

It is important to keep in mind that the *raison d'être* of IPRs is to foster innovation and productivity growth. The key factor that determines the long-term, sustainable economic impact of innovation is the non-appropriability of some of the benefits of innovation.[3] Although economists have modeled

[3] The traditional growth model developed by Solow (1956) posits that national growth is a function of the accumulation of labor and capital, with technological change exogenous to the model. Given that labor supply is largely a function of population growth, the only stochastic variable is capital accumulation, which is a function of the marginal product of capital and the inter-temporal discount rate. This traditional growth theory argues that the marginal product

the effect of general or applied science innovations differently, the results converge to a common view. Theory assumes that, even with IPRs, at least part of the non-rival knowledge accumulated is non-excludable (e.g., the know-why, know-how, and know-who elements). With technological change, non-excludable knowledge, what Romer (1990) describes as the "improvement in the instructions for mixing together raw materials", spills over into the economy as a whole and raises the marginal social value of the new innovation. And so the positive externality associated with investing in innovation leads to a sectoral or national production function with increasing returns to scale. In essence, the rate of growth in the economy rises with the degree to which innovations are non-excludable, with the amount of resources devoted to innovation activity (i.e., R&D organizations, public education institutions and entrepreneurial spirit) and with a lower inter-temporal discount rate (i.e., the longer the time horizon of investors).

Ultimately, growth is reflected in the incomes of producers and consumers. The conventional view is that yield-enhancing research ultimately benefits consumers more than producers, while quality-enhancing innovations, in contrast, provide greater benefits to farmers (Alston et al., 1998b). Moschini and Lapan (1987) use theory to show that private IPRs and non-drastic innovation make IPR holders the only beneficiaries. Recent studies show that, in practice, a significant portion of the benefits go to consumers: Moschini et al. (1999) apply the theory to the introduction of Roundup Ready soybeans, concluding that, even with a non-drastic innovation, productivity rises, prices fall and consumers gain. However, not all farmers will gain. Fulton and Keyowski (1999) conclude that, because farmers differ in their agronomic practices, some will gain and others will lose.

While governments are interested in higher welfare through lower prices, they are particularly interested in the observation that, if any of the spillovers are locationally tied, then creating local capacity that attracts that research may put that jurisdiction on a higher value growth path (Grossman and Helpman, 1991). Zucker et al. (1998) concluded that local agglomerations of public-sector and university research stars created just those conditions,

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of physical capital declines as the ratio of capital to labor rises. Thus, the incentive to invest declines as an economy grows. At some point, then, aggregate capital investment will converge to a constant (the replacement of capital level) resulting in the stabilization of long-term economic growth at the rate of growth in the labor force. Both international gross domestic product (GDP) levels and growth rates would also converge due to this process. The empirical evidence shows, however, that something is missing from this specification. Growth in per capita incomes has been sustained globally and nationally for long periods above the rate of growth in labor. Grossman and Helpman (1991) note that studies show the Solow model only explains about 20 to 50 percent of measured growth and performance has varied greatly from country to country.

attracting clusters of private-sector activity around the core. Phillips and Khachatourians (forthcoming) have also observed this phenomenon in the global canola sector in recent years. Although the R&D benefits would thereby be captured in discrete jurisdictions, the spillovers and resulting accelerated innovation should ultimately benefit consumers everywhere.

For these reasons, the public sector has a large role to play in encouraging economic growth. Public organizations have access to large pools of financial resources, pursue non-excludable innovations from which the benefits are not expected to be privately appropriable and maintain a very long-term investment horizon. Evidence suggests that few developing countries have achieved the level of capacity necessary to attract private investment (FAO, 1998). Weak levels of protection for new ideas further exacerbate this problem.

5.5 IPRs and Industry Structure

The desire to privately appropriate the returns on intellectual property has been a fundamental impetus to structural change in the agri-food industry. The advent of IPRs, as discussed above, created potential risk and opportunities for the agri-food sector. The industry has restructured both to exploit IPRs and to overcome the difficulties of accessing proprietary technologies. Perhaps most dramatic was the industrial restructuring that occurred in the chemical sector itself. As Just and Hueth (1993) point out, chemical firms had an incentive to invest in genetics to protect the value of their IPRs in patented herbicides. As a result, almost all of the large chemical companies moved to partner their agri-chemical divisions with genetics and seeds units, spurring the creation of multinational life-science companies. In just a few years almost all of the entrepreneurial biotechnology firms and most of the independent seed companies have been acquired and integrated into one of the life-science companies. Now Monsanto, Aventis, Advanta, DowAgrosciences, BASF, DuPont and Novartis dominate the market, extending their reach through strategic alliances into the major grain and oilseed companies (e.g., Cargill and Archer Daniels Midland). This oligopolistic market structure, bordering on monopolies in certain crop areas, has overcome some of the hold-ups in accessing and commercializing innovations, but at a significant cost. Uncompetitive market structures impose both social and commercial costs, and these are only now being considered.

5.6 IPRs, Adoption, Diffusion and Trade Flows

International market access for new products is becoming the most important issue in developing knowledge-based (e.g., biotechnology) products. In the past, governments limited or denied international market access in an effort to achieve a variety of economic and social objectives such as domestic income support, increased production and export earnings. In the knowledge-based world, time is money. Research-intensive production, short product life-cycles and niche markets combine to make it commercially imperative that products enter the marketplace with the widest possible access and at the earliest opportunity. A delay of just one growing season can substantially reduce the expected return on new products (Heller, 1997).

At the same time, as the total research effort into crops has increased, production has begun to shift towards countries that are intensively managing crops as knowledge-products and away from countries that are not competing on the knowledge frontier. In canola, for instance, the European Union and Canada, both leaders in the R&D of canola, have doubled to 40 percent their share of global production over the past 30 years. Together they account for more than 86 percent of world exports. Meanwhile, India, Pakistan, Poland and Japan have invested little in R&D for new canola-related technologies or varieties and have seen their share of global production drop to about 23 percent in 1992-96 compared with 50 percent in 1961-65. In addition, a number of new producers are on the horizon with commercial quantities of canola. The United Kingdom, the US and Australia, all significant investors in canola-related research, are notable for entering and significantly expanding their market shares in the 1980s (equal to 6 percent of global production in 1992-96).

Global statistics mask a potentially more important trend. When crops become innovative goods, they begin to exhibit product attributes, which leads to two-way trade between producing and consuming countries. In the canola sector, one reason for the increase in intra-sectoral trade is that net importers continue to produce rapeseed quality output but desire to purchase canola quality seed for human consumption. Two-way trade is already being observed in Canada and Australia, where canola varieties with different agronomic and oil properties are proliferating (Phillips and Khachatourians, forthcoming). Given that each of these varieties is effectively a niche product with a limited global market, there is increasing potential for traditional net exporters to export and import different novel varieties.

The end result of these market changes is a global industry that depends heavily on international trade. Production of the commodity product, which should theoretically only flow from producing to consuming countries, is now flowing to a larger number of countries since domestic demand tends to outstrip production capacity. This is exacerbated in less developed countries, for which the technology and productivity gap with research intensive countries is widening. Moreover, the emergence of international markets for research-based, differentiated and novel canola products raises the potential and need for more intra-sectoral trade. All of these trends highlight the importance of "getting the institutions right" so that the effective functioning of the international trade regime and the innovation investment required for continued economic growth can be ensured.

6 CONCLUSION

The economic implications of new or strengthened IPRs have broad and far-reaching consequences. Three key points are worth making.

First, it is critically important that developing countries pay careful attention to the design of their research policy. Although it may be true that some positive spillovers may result from private innovation investments, the object of that private expenditure is to produce private, excludable innovations. Greater positive spillovers and higher social benefits are likely to result from the production of less excludable items. Therefore, public-sector investments should create the institutions necessary for public-sector researchers to pursue long-run, non-excludable innovations. There are two elements of research policy to be considered: (i) Because publicly-provided research can push R&D investment in targeted areas past the socially optimal point, the support and direction given for the direct performance of public research ought to be carefully examined to ensure that public innovation activity does not simply accelerate or replace private activity. (ii) Any public program must consciously design a regulatory framework that provides private actors with a sufficient assurance of future excludability to "pull" innovations but that does not sacrifice an unacceptable quantity of the social good. Developing countries need also to think about the role of public research expenditures in helping to gain a competitive advantage in product areas. For countries that need to close a "technology gap", there is no choice. These countries cannot rely solely on publicly funded research. They need private capital and knowledge. A country trying to achieve technological "catch-up" must invest in public research that complements private research activities in order to attract private activity and capture the greatest positive spillovers. Without research programs focused on local needs, it is likely that agricultural productivity growth in many of these countries will lag due to an inappropriate fit between innovations and local conditions.

Second, developing countries must accept that the time is past for deciding whether or not to institute an IPR regime. Trade agreements mandate them, the industrial structure necessitates them, and economics confirms their efficacy. It is no longer feasible for small- or medium-sized countries to go-it-alone; in order to be competitive, countries must encourage the maximum flow of knowledge. The real question today is where to place constraints on the monopolies resulting from IPRs. These constraints can be imposed through various means, including anti-trust laws, compulsory licensing, rules allowing for expropriation and policies related to the buying-out of exclusive use-rights. The only condition is that as the restraints rise, the level of private activity will fall.

Finally, the increase in two-way trade is inevitable and a sign of the wide ranging economic importance of biotechnology products. Market access, then, may be the ultimate determining factor for the quantity of private investment in agri-food innovation. Any access restrictions on biotechnology products may be counterproductive, since it forces large multinational corporations to cut expenditures on innovation related activities and thereby jeopardize both the social and consumer benefits of innovation.

REFERENCES

Alston, J.M., M.C. Marra, P.G. Pardey, and T.J. Wyatt (1998a): Research Returns Redux: A Meta-Analysis of the Returns to Agricultural R&D. Environment and Production Technology Division Discussion Paper, No. 38, International Food Policy Research Institute, Washington, D.C.

Alston, J.M., G. Norton and P.G. Pardey (1998b): *Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*. CAB International, Wallingford, UK.

Canola Council of Canada (1999): Canola Connection. Report retrieved from the internet: www.canola-council.org/index.shtml.

FAO (1998): State of the World's Plant Genetic Resources for Food and Agriculture. Appendix 1, Food and Agriculture Organization of the United Nations, Rome.

Fulton, M., and L. Keyowski (1999): The Producer Benefits of Herbicide-Resistant Canola. *AgBioForum* 2 (2), paper retrieved from the internet: www.agbioforum.missouri.edu/.

Gadbow, R., and T. Richards (eds.) (1990): *Intellectual Property Rights – Global Consensus, Global Conflict?* Westview Press, Boulder.

Gray, R., S. Malla, and P. Phillips (1999): Gains to Yield Increasing Research in the Evolving Canadian Canola Research Industry. Paper presented at the conference

"The Shape of the Coming Agricultural Biotechnology Transformation", 17-19 June, Tor Vergata University, Rome.

Grossman, M., and E. Helpman (1991): *Innovation and Growth in the Global Economy*. The MIT Press, London.

Heller, J. (1995): James G. Heller Consulting, June. Quoted in J. Goudey, and D. Nath (1997): Canadian Biotech '97: Coming of Age. Ernst & Young, Toronto.

Just, R.E., and D.L. Hueth (1993): Multimarket Exploitation: The Case of Biotechnology and Chemicals. *American Journal of Agricultural Economics* 75 (4), pp. 936-945.

Locke, J. (1690): *Of Property; The Second Treatise of Government*. Reprinted in 1988, Cambridge University Press, Cambridge.

Malecki, E. (1997): *Technology and Economic Development: The Dynamics of Local, Regional and National Competitiveness*. Longman, Toronto.

Marshall, A. (1890): *Principles of Economics*. Macmillan, London.

Moschini, G., and H. Lapan (1997): Intellectual Property Righrs and the Welfare Effects of Agricultural R&D. *American Journal of Agricultural Economics* 79 (4), pp. 1229-1242.

Moschini, G., H. Lapan, and A. Sobolevsky (1999): Trading Technology As Well As Final Products: Roundup Ready™ Soybeans and Welfare Effects in the Soybean Complex. Paper presented at the conference "The Shape of the Coming Agricultural Biotechnology Transformation", 17-19 June, Tor Vergata University, Rome.

OECD (1996): *The Knowledge Based Economy*. Organization for Economic Development and Cooperation, Paris.

OECD (1999): Policy Brief. Organization for Economic Development and Cooperation, Paris.

Phillips, P. (forthcoming): The Role of Intellectual Property Rights in the Canola Industry. In: G. Carlson et al. (eds.). *Agriculture and Intellectual Property Rights: Economic, Institutional and Implementation Issues in Biotechnology*. CAB International, Wallingford, UK.

Phillips, P., and G. Khachatourians (forthcoming): The Biotechnology Revolution in Global Agriculture: A Case Study of Innovation, Invention and Investment in the Global Canola Sector.

Romer, P. (1990): Endogenous Technological Change. *Journal of Political Economy* 98 (5), Part 2, pp. 71-102.

Romer, P. (1995): Beyond the Knowledge Worker. Worldlink (January/February), retrieved from the internet: www~leland.stanford.edu/~promer/wrld_lnk.htm.

Schumpeter, J. (1954): *Capitalism, Socialism, and Democracy*. George Allen and Unwin, London.

Solow, R. (1956): A Contribution to the Theory of Economic Growth. *Quarterly Journal of Economics* 70 (1).

Smith, A. (1776): *An Inquiry Into the Nature and Causes of the Wealth Of Nations*. Random House Inc., New York.

US Patent and Trademark Office (1999): Patent Database. Information retrieved from the internet: www.patent.womplex.ibm.com/.

UPOV (1999): About UPOV. Union for the Protection of New Varieties of Plants. Retrieved from the internet: www.upov.int/eng/content.htm.

Zucker, L., M. Darby, and M. Brewer (1998): Intellectual Human Capital and the Birth of U.S. Biotechnology Enterprises. *American Economic Review* 88 (1), pp. 290-306.

Chapter 17

INTELLECTUAL PROPERTY RIGHTS ISSUES AND DEVELOPING COUNTRIES: A PRIVATE-SECTOR PERSPECTIVE

Andrew Beadle

Abstract: The activities in agricultural biotechnology are progressing rapidly, but the benefits of this new biological revolution have not yet reached the poorest parts of the world. One reason is that developing countries lack intellectual property rights (IPRs) protection, which limits the private sector's ability to introduce cutting-edge technology to these countries. Strengthened IPRs at the national level do not just serve the current net exporters of technology; in the long run they also promote sustainable economic growth in developing countries. Companies from the developed world have a role to play in the targeted transfer of technologies and know-how to local agencies in the developing world that can support subsistence farmers. These technologies must be in a form that can help improve the quality of life of the local population. Only then can we say that the developed world is helping to optimize the benefits of biotechnology for the poor.

1 INTRODUCTION

Developed nations have placed great emphasis on the global protection of all types of intellectual property. This is particularly true in the modern agri-business marketplace, where the successful application of biotechnology has had and should continue to have dramatic effects on some aspects of agriculture and food production. These advances, however, are increasingly subject to intellectual property protection as academic, governmental and industrial communities seek to protect their research and development (R&D) investments. Intellectual property rights (IPRs) are usually protected by one of three legal instruments: copyrights, trademarks or patents. In the field of agriculture there is an additional instrument: plant variety protection (PVP) that protects new varieties of sexually reproducing

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plants. Generally, however, PVP is sought for plants that have been derived from traditional breeding activities and not for plants that have been genetically modified through recombinant DNA techniques.

Biotechnology companies, universities and public research institutes are spending large amounts of resources in R&D. As a result, biotechnology continues to develop at a rapid pace – new discoveries, genes, traits and potential applications are being applied to an increasing number of crops worldwide. Between 1996 and 1999, twelve countries (eight industrial and four developing) have contributed to a more than twenty-fold (23.5) increase in the global area of transgenic crops. In 1999, the global area of transgenic crops increased by 12.1 million hectares (44%) to around 39.9 million hectares. Seven transgenic crops were grown commercially in twelve countries in 1999, three of which, Portugal, Rumania and Ukraine, grew transgenic crops for the first time (James, 1999).

Transgenic crops have the potential to play a major role in the economic development of low- and middle-income countries. These countries, in theory, have much more to gain from the application of biotechnology because the areas currently under agricultural production are far greater than in the industrialized world. In addition, yields of almost all crops are significantly lower in developing countries, principally due to the stresses (i.e., drought, salinity, pests, diseases etc.) that biotechnology and transgenic crops could help to reduce. And finally, there is the issue of food security. The International Service for the Acquisition of Agri-biotech Application (ISAAA) has estimated that during the next decade an increase in productivity of between 10-25 percent from transgenic crops is both feasible and realistic. This, in combination with conventional crop improvement applications, could help to provide food where it is most needed and to deliver sustainable farming practices for the benefit of all.

But despite this accelerated activity in the field of biotechnology, the benefits of this new biological revolution have yet to reach those parts of the world that need it most. The lack of intellectual property laws and frameworks, coupled with licensing concerns and inadequate infrastructure for developing the new technologies (such as robust regulatory packages and the introduction of biosafety measures), limit the private sector's ability to introduce cutting-edge technology to developing countries. For example, breeding new varieties of plants requires a substantial investment in terms of skills, time and financial resources. To protect this investment, a successful plant breeder has a better chance of recovering his or her costs and accumulating the funds necessary for further investment through such regulations as PVP protection, which provide certain exclusive rights for new varieties. In the absence of plant breeders' rights, those aims are more difficult to achieve because there is nothing to prevent others from multiplying the seeds or other propagating material and selling the variety on a commercial scale – without recognizing in any way the work of the breeder.

In recent years, developed nations have placed great emphasis on the global protection of intellectual property. In 1994, this led to the adoption of the Agreement on Trade Related Aspects of Intellectual Property Rights (known as TRIPs), part of the Uruguay Round of trade negotiations. Adhered to by more than 100 countries, TRIPs requires member states, with only certain time-restricted exceptions, to provide a high level of IPRs and to promote mechanisms for their effective enforcement.

A principal argument advanced by developed countries for protecting and enforcing IPRs is that intellectual property leads to innovation, which, in turn, will lead to greater international trade, which will benefit everyone. Given that developed nations are currently the major net exporters of intellectual property, however, the argument appears at face value to be purely self-serving. It could be argued, for example, that such protection clearly increases the exports from the developed world while keeping pirated products out of the developing markets. Through specific examples, this paper seeks to demonstrate that companies like Novartis are keen to transfer proprietary technology to developing countries for use by subsistence farmers for the immediate needs of the local population. Indeed, they have already taken proactive steps to do so. Many multinationals are working at the local level to raise awareness about intellectual property management and licensing issues so that, once workable systems are put in place by national authorities, both parties can seek to fully exploit future market opportunities.

2 IPRs IN DEVELOPING COUNTRIES

IPR protection becomes more complex when producers and users of knowledge are in different countries with different economic levels of development. It is far from clear that all countries should be required to maintain the same level of intellectual property protection. If a country has limited innovative capability and primarily consumes foreign innovations, stronger intellectual property protection may in the short-term lead to consumer welfare losses and may discourage innovation and economic adaptation by competitors. For example, in some developing countries with patent systems, patent protection was not allowed on certain products such as pharmaceuticals. The absence of patents enabled infant industries to examine and copy products and to develop a local production base. This course of action could potentially limit inward investment, but it would produce the necessary local infrastructure and trained personnel in the long-term to fully exploit future opportunities as they arise in mutually beneficial partnerships.

The counter argument to this is that IPRs equate knowledge producers with commercial and research-based developers. For example, farming communities in developing countries produce knowledge about local plants and their adaptations to specific environments. Stronger IPRs may increase the incentives for local research efforts and increase interactions with end-product producers. Yet the lack of in-depth intellectual property management skills and experience constitutes a significant barrier to the effective adoption and transfer of biotechnological applications in developing countries in the short-term. All parties need to be able to negotiate agreements to use emerging technologies. They also need to participate in the continuing debate about particular forms of intellectual property to ensure that personal and institutional interests as well as those of the developing country are taken into account. It is this lack of technical knowledge and expertise in the acquisition of plant variety protection, patents and other legal mechanisms required for the maximum commercial viability of improved agricultural varieties that is holding back developing countries at a time when the obligations of TRIPs require the signatories to provide minimum national protection standards. Such protection must cover: copyrights and related rights, trademarks, geographic indications, industrial designs, patents (and PVP), protection of undisclosed information and control of anti-competitive practices in contractual licenses.

3 EFFECTIVE IPR PROTECTION WILL ULTIMATELY INCREASE TRADE AND DEVELOPMENT FOR LESS-DEVELOPED COUNTRIES

International trade in intellectual property encompasses a wide range of industries, including biotechnology. All industries rely, to a great extent, on the protection awarded by copyright, trademark and patent laws. For the reasons listed below, all countries, including less-developed countries, should aggressively and effectively protect intellectual property.

- The most important reason for a country to protect intellectual property through adequate laws and aggressive enforcement is economic. If a country does not protect intellectual property, it is far less likely that it will develop its own farming industries. The encouragement and development of local breeders, scientists and developers depends to a great extent on their ability to earn a living from their work. Without such protection, local intellectual property is less likely to be created, and the developing country may be permanently relegated to the role of net importer of intellectual property.

- Multinational companies that need intellectual property protection for their products are reluctant to locate in countries that do not offer some form of protection.
- While the reluctance to locate a production plant in a certain country may appear speculative, the reluctance to ship products to such a country is not. Many companies that work with intellectual property are, in fact, reluctant to distribute in countries that do not protect IPRs. If their property cannot be protected, they will frequently refuse to license legitimate distributors and will simply ignore the market. This means that legitimate, homegrown, taxpaying channels of distribution will not develop inside the country. Nor will the country develop domestic expertise in licensing and distribution. Instead, illegal importers or duplicators will supply the market.
- The market of a country that does not protect intellectual property will tend to be flooded with inferior illegitimate products. This is true not only for computer software but also for other products, such as patented pharmaceutical and biotechnological inventions in which copyrighted or patented material is basic to the product. Thus, while the availability of pirated products may seem an economic advantage in the short term, in the long term it will inevitably impede a country's development.
- Complying with international law requirements to protect intellectual property is important not only if a country wants to be a participating member of the world community, but also if the country wishes to avoid trade sanctions that can have economic impacts on trade far beyond the boundaries of IPRs. The TRIPs agreement does contain transitional provisions that exempt "developing country members" and "least developed country members" from certain requirements, including product patent protection for a limited number of years. However, even if such exemption is permitted, and a country therefore does not face sanctions for its failure to immediately follow all the TRIPs mandates, it may not be in a country's best interest to take advantage of these transitional provisions for long. If one believes that it is ultimately to the economic benefit of every country to protect intellectual property, the longer the exemption in the transitional provisions is used, the greater will be the long-term economic harm to that country.

4 THE ROLE OF INDUSTRY IN PROMOTING SUSTAINABLE DEVELOPMENT IN DEVELOPING COUNTRIES

Industry (in this context the biotechnology industry) working in partnership with local, on-the-ground organizations, can put in place various mechanisms to improve the socioeconomic conditions of developing countries. Here are some suggestions:

- Industry and local agencies should strive to attain biotechnological and agronomic solutions that are both socially and economically acceptable.
- The provision of proprietary materials to developing countries should address specific needs and requests on a case-by-case basis.
- The provision of proprietary technology should not encourage the persistence of an economic or social state of farmers. Ideally, it should lead to a "development" of the country's economy or of individual farmers.
- Industry should work with local authorities to develop the best packages for the immediate needs.

And here are some examples of what can be accomplished through partnerships between the private and public sectors. In 1998, Novartis and a number of other multinational donors signed an agreement with ISAAA to facilitate the transfer of crop biotechnological applications to increase and sustain the production of food, feed and fiber in developing countries (with particular emphasis on Southeast Asia and Latin America). The specific aims of the agreement are to:

- meet the needs and priorities of developing countries towards increased food security, income generation and a better quality of life while facilitating environmentally friendly farming practices;
- contribute to raising awareness about the value of IPRs in developing countries;
- develop pilot projects with ISAAA to connect key decision-makers in relevant developing countries;
- undertake and contribute to training projects on biosafety and IPRs;
- assist in the identification of private-public and private-private connections;
- train national scientific and technical staff in private laboratories;
- facilitate the early adoption of efficient and appropriate field-testing regulations for transgenic crops in Southeast Asia and elsewhere; and
- build biotechnology competence and capacity in key national programs.

Working with international research agencies such as the International Rice Research Institute (IRRI) and others, Novartis has made a range of biotechnological principals available to developing countries. Novel second-generation products, such as the Novartis positive selection technology (which utilizes sugars as a selection medium for transformed crops), are also being made available to developing countries at the same time as they are introduced to the developed world.

The aim of such technology transfer initiatives is to help build national capacities in plant biotechnology. Working in close cooperation with national agencies in the framework of specific projects, companies can help in the development of operational and effective biosafety regulatory mechanisms through capacity building. They can also help nurture IPR knowledge and experience in developing countries by providing training and hands-on experience. Finally, collaborations with the private sector to build biotechnology transfer capacity would demonstrate the benefits of proprietary technology, sensitize scientists and senior policy-makers to IPR issues and create trusting relationships that will facilitate new and better solutions.

5 CONCLUSION

It is in the long-term economic self-interest of developing countries to protect the intellectual property of all nations. To achieve this goal, emphasis must be placed not only on enacting intellectual property laws, but also on making certain that these laws are effectively enforced. In addition, companies from the developed world have a role to play. They can contribute their wealth of experience in all of the support packages and infrastructures required for developing transgenic crops to those local agencies that can support subsistence farmers in a targeted, effective and efficient transfer of technology and know-how. The technology must be in a form that can help improve the quality of life of the subsistence farmer, so that he or she can start to contribute to economic growth and prosperity of the home country. Only then can we say that the developed world is helping to optimize the benefits of biotechnology for the poor.

REFERENCES

James, C. (1999): Global Review of Commercialized Transgenic Crops: 1999. ISAAA Briefs, No. 12, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

Chapter 18

INTELLECTUAL PROPERTY RIGHTS CHALLENGES AND INTERNATIONAL RESEARCH COLLABORATIONS IN AGRICULTURAL BIOTECHNOLOGY

Brian D. Wright

Abstract: The international strengthening of intellectual property rights (IPRs) has stimulated many private and public research organizations to develop new agricultural biotechnology applications. The scope for further innovation is huge. But there is also a downside to the escalation of IPRs: access to important research tools becomes increasingly restricted and the costs of consummating licensing deals may become prohibitive. As patenting activity progresses, the number of separate rights needed to produce a new innovation proliferates. Due to the lack of resources, specific expertise and clear strategies the international agricultural research centers (IARCs) are placed at a particular disadvantage in bargaining over proprietary rights. Different options are discussed that could help to turn the contracting disadvantages of IARCs into new opportunities for technology transfer. Many of the transaction problems are shared by the large human health research complex, so contractual innovations in that area should be followed closely.

1 INTRODUCTION

The current revolutions in biotechnology and information technology are transforming the potential for progress in agricultural research. In doing so, they have also increased the benefits of cooperating with others on the frontiers of international science. At the same time, proprietary claims are rapidly enveloping the tools that researchers need to partake of the new opportunities. In this paper I address some implications of the current state of intellectual property rights (IPRs) for international collaborations in crop

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breeding, collaborations that over the past half-century have been very productive for the world's food consumers. Given the dynamics of the current situation, this paper is part report from small segments of the frontline and part analysis of policy options. The institutions I have in mind include the international agricultural research centers (IARCs), especially those that are members of the Consultative Group on International Agricultural Research (CGIAR), and also major national agricultural research systems (NARSs) involved in non-profit crop breeding.

2 THE EVOLVING INTERNATIONAL ENVIRONMENT FOR CROP RESEARCH

In the past half-decade, the dynamic interactions of revolutions in biotechnology, international trade agreements, and law have begun to transform the environment for international agricultural research collaboration. These revolutions gathered strength in the United States in the 1980s and burst upon the international scene in the 1990s, a decade in which the domination of the United States, as the leader in world innovation and in international rule making for trade and intellectual property, reached new heights.

In the years between World War II and the 1990s, IPRs had little relevance for international agricultural research, which was, and is, focused mainly on plant breeding. This does not mean that the plant breeder's world has traditionally been one of free international exchange. The situation in the post-war years was an historical anomaly. From time immemorial, nations have jealously guarded access to plants or animals that gave them national advantages over their rivals. As detailed by Juma (1989), the nineteenth century colonial powers pursued and defended such advantages to the full. Others tried strenuously to breech national germplasm monopolies. For example, Thomas Jefferson is said to have risked the death penalty by smuggling Piedmontese rice seeds in the lining of his coat.

But historical monopolies over plants and animals have been national rather than private. Domestically, private breeders have traditionally received scant protection. Even in the US, the country most sympathetic to private claims on innovations, there was no legal restriction on the use of genetic resources for breeding to produce new cultivated varieties ("cultivars") of plants until the twentieth century. The seeds that breeders used, and their methods of breeding, were protected, if at all, only by state trade secrecy laws.

There is a longer history of protecting some crops from unauthorized reproduction of cultivars (as opposed to breeding new ones) in developed countries. The US Plant Patent Act of 1930 protected many clonally propagated plants from unauthorized cloning for the life of the patent. This protection was useful principally in horticulture. Much later, via the introduction of the Plant Variety Protection Certificate (PVPC) in the Plant Variety Protection Act of 1970, some restrictions were placed on the use of sexually propagated seed for replanting. Farmers were allowed, however, to save seed for their own use and to engage in limited sales for planting by others. Furthermore, the use for breeding of new cultivars was unrestricted, as long as the new cultivars were distinct varieties, even if the distinguishing feature (for example, a difference in flower color of a soybean) was of no agricultural significance.[1]

The lack of IPR protection for plants was not due to a lack of interest by the Patent Office in incentives for improvements in crop and livestock. Until the 1980s, stronger legal protections on plant breeding innovations would likely have been irrelevant. Until the advent of biotechnology, verifying the parentage claims of new, distinct cultivars was problematic. Claims over heritable traits were similarly unenforceable. Recognizing the lack of private incentives for supplying new cultivars, the US Patent Office in the nineteenth century supported public crop-improvement efforts, including the collection and dissemination of seed varieties from other countries (Huffman and Evenson, 1993).

Until the advent of biotechnology, the only effective protection against the use of privately developed germplasm for breeding successive generations of crops was the production of hybrids that do not breed progeny sufficiently high-yielding to encourage replanting. In the case of United States corn, the most prominent example, this protection was strong enough to foster the growth of a profitable private seed industry well before the strengthening of effective, legal means of intellectual property protection in plants.

In the 1980s, the US federal patent law administration was reorganized in a way that effectively gave more weight to the claims of innovators. At the same time, the Supreme Court expanded the class of patentable subject matter to new life forms (*Diamond vs. Chakrabarty*, 447US303, 1980). In 1985, the *ex parte* Hibberd ruling confirmed the patentability of seeds, plants and tissue. Such materials have consequently been included under the rubric of "intellectual property".

In the same half-decade, the class of possible patentees was also significantly expanded in the US. The Bayh-Dole Amendment (1980)

[1] Although the revised 1994 PVPA introduced the concept of an "essentially derived variety" and extended the possible scope of protection, the protection is still believed to be insufficient to encourage adequate private investment in crop breeding.

confirmed the rights of researchers to take out patents on federally funded research, just in time to allow Cohen and Boyer to patent their Nobel prize-winning recombinant DNA technology. The subsequent decades have yielded a flood of patentable innovations in biotechnology products and processes in the US, many of which originated in university research supported by public health-related grants (Lehne and van Roozendaal, 1995). Innovations for some genes, promoters, markers and means of transformation proved extremely useful in crop breeding, but they were proprietary. Patents were also claimed for new plant cultivars, including the inbred parent lines used, for example, by hybrid corn breeders.

The revolutions in biotechnology and intellectual property protection coincided with a slowdown in the trend of federal and state funding for agricultural research in the US (Alston et al., 1999). In the first generation of commercialization, many individuals in non-profit research institutes and academia saw in the Bayh-Dole Act a source of financing for research. There was also the hope that the prospect of patentability might motivate researchers to make their research more relevant to the needs of the commercial sector and that it would encourage more effective commercialization of research results.

Universities everywhere created Offices of Technology Licensing (or Transfer), and formulae were established that gave patentees a substantial share of revenues generated by their patents. The paradoxical consequence is that a professor at a public university can now anticipate a much higher direct benefit share from any patent she files than a researcher employed by a typical private company. Furthermore, professors are allowed, and often encouraged, to form startup corporations, in collaboration with venture capitalists, to exploit the fruits of their research. The incentives have proved strong and effective; the rewards of success are in fact very generous in many cases. As a result, many new biotechnology applications have been developed in the US and in other countries that followed a similar path. Crop breeders now have many more tools to work with, and the scope for further innovation is huge. But breeders in the US now find that the inputs they want to use are caught in a tangle of IPR claims; the same problem is spreading to other countries.

3 INTERNATIONAL PROLIFERATION OF PROPERTY RIGHTS PROTECTION FOR AGRICULTURAL BIOTECHNOLOGY

The legal and biotechnological foundations laid in the US in the 1980s produced an explosion of plant-breeding biotechnologies and also initiated an international trend towards stronger IPRs for crop breeding inputs and outputs. US negotiators accelerated this trend by insisting on the international expansion and strengthening of intellectual property protection at the Uruguay Round of the General Agreement on Tariffs and Trade (GATT) negotiation. They used the benefits of world trade reform as the bait. Under Article 27.3(b) of the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPs) (Contracting Parties to the GATT Uruguay Round, 1994), all members of the World Trade Organization (WTO) must adopt a patent system or other *sui generis* systems of intellectual property protection for plants and other life forms.

Developed countries have, in most cases, opted for patent protection. In 1998, the European Parliament approved a proposal for a European Directive on the Legal Protection of Biotechnological Inventions, which must be implemented by member countries within two years. This directive, which is the subject of ongoing controversy, permits the patenting of genetic material, including groups of plant or animal varieties for which application of an invention is feasible (Leskien, 1998). In many countries, protection includes a system of plant variety protection similar to the 1994 revision of the US PVPC, in line with the 1991 Convention of the International Union for the Protection of New Varieties of Plants (UPOV), which came into force in 1998 (Ghijsen, 1998). It is commonly understood that *sui generis* systems of plant variety protection similar to that provided under UPOV will be acceptable under TRIPs, and many developing countries are adopting such systems.

As is typical in areas of rapidly evolving technology, the scope and strength of patent protection in agricultural biotechnology, and indeed in biotechnology more generally, are not yet firmly established, even in developed countries. Broad claims to applications of genetic engineering in a given species, as seen in patents granted in the US to Agracetus in 1992 for cotton, and in 1994 for soy (e.g., RAFI, 1994; Powledge, 1995), may well be invalidated eventually, as was a broad Indian cotton patent in 1994 (van Wijk, 1995). Patent claims covering methods of genetic transformation of corn and the products thereof have been invalidated in several prominent federal cases in the US over the past few years.

On the other hand, no one can know for sure whether the flood of patent applications for nucleic acid sequences – 500,000 in one year (Enriquez, 1998) – associated with the genomics revolution of the past several years will in the long run be deemed patentable. Nor do we yet know how many of these will be privately held. Researchers using the methods and products of genetic engineering might be well advised to seek to identify any prior proprietary claims that could affect their work. But they must also recognize that, despite their best efforts, they cannot be certain that any of the intellectual property claims to some of their research tools will be deemed valid in the end (after any court challenges are finally resolved), and if claims overlap, which will dominate.

Advances in biotechnology have also strengthened other traditional means of protecting plant breeders, such as trade secrecy. Before the revolution in biotechnology, hybrid plant producers were protected from misappropriation by their customers through the replanting of commercial hybrids. The inbred parent lines, however, were vulnerable to acquisition and use by other breeders. Indeed, within the US seed corn industry, it is widely recognized that breeding material from Pioneer has made its way into the genetics of prominent competitors. Some of this occurred via "flashlight breeding", the taking of parent-line seed from a strand of corn in a contract-farmer's field using a flashlight at night. Using the genetic fingerprinting made possible by the early advances in biotechnology, Pioneer Hi-Bred International was able to win a law suit under Iowa's trade secret law against Holden's Foundation Seeds, receiving US $47 million in damages (*Pioneer Hi-Bred v. Holden Foundation Seeds*, 35F3d1226, 1994). More recently, an allegation by Pioneer against Cargill, involving the misappropriation of breeding materials by a scientist hired away from Pioneer, led to the collapse of a US $650 million sale of Cargill's domestic seed business to AgrEvo. Pioneer (recently acquired by DuPont) has also sued other major seed producers for searching for self-pollinated (parent cultivar) seeds in bags of commercial hybrids and using them for breeding, in violation of the bag-label contract which prohibits use for seed breeding. Such "reverse engineering" would not appear to violate patent laws. If Pioneer prevails, the bag label contract will be more firmly established as a way for seed producers to expand control over their inbred lines and perhaps over their self-pollinated varieties as well.

Monsanto is another firm using biotechnology to strengthen its assertion of property rights. In early 1999, it reportedly had pursued 525 cases in the US and Canada involving illegal replanting of seed, about half of which have been settled, many for tens of thousands of dollars (Weiss, 1999). In one celebrated case, Monsanto is suing a Canadian farmer for planting transgenic canola in violation of Monsanto's patent rights. Monsanto also introduced the concept of a Technology Use Agreement that confers the right to plant Monsanto's transgenic seed for one season on a designated area of land. This innovation is interesting for economists as it avoids the distortion of seeding rates inherent in rent collection via seed sales. But Monsanto's attempts to exercise its contractual right to on-farm inspections (including using biotechnology for the testing of plants for the presence of transgenes) and its encouragement of neighbor-informants were perceived as violations of respect for privacy. They engendered great farmer resentment in the US and might be no more welcome in other countries.

Widespread opposition has recently led Monsanto to abandon commercializing its so-called "terminator" technology, which had the potential to prevent replanting of (non-hybrid) saved seed by farmers and to greatly enhance the enforcement of property rights held by plant breeders (Kaiser, 1999). The CGIAR (1998) already rejected this technology, supporting instead research on apomixis, the non-sexual reproduction of seeds that could be used to make the benefits of hybridization available without hindering replanting of seed. In this case, the biotechnology could reduce the value of the rights associated with hybrid seeds.

4 THE RISE OF FARMERS' RIGHTS

As a complement to its efforts to internationalize respect for broad intellectual property rights, the US encouraged a change of policy for the countries of the South in negotiations regarding access to genetic resources in the 1980s. Initially, as expressed in Article 1 of the International Undertaking on Plant Genetic Resources of the Food and Agriculture Organization (FAO) of the United Nations in 1983, the South advocated that plant genetic resources be: "explored, preserved, evaluated, and made available for plant breeding and scientific purposes. This Undertaking is based on the universally accepted principle that plant genetic resources are a heritage of mankind and consequently should be available without restriction" (FAO, 1983).

The principle articulated in this statement formed the basis of highly successful international collaborations that have achieved impressive yield increases in the major food crops of wheat and rice over the last two decades. The major beneficiaries were the consumers of these crops, most of whom reside in less-developed countries (LDCs). Profits from seed production are relatively insignificant in these crops. Since Article 2 of the undertaking extended access to new cultivars and elite breeders' lines produced by the private sector, in particular by breeders of hybrid crops, especially corn, the policy was inconsistent with the United States' effort to extend intellectual property protection to private agricultural biotechnology.

Subsequently, the focus of countries of the South shifted to assertion of "farmers' rights" to their traditionally cultivated varieties ("landraces") and to their contributions to the production of commercial cultivars as expressed in the Convention on Biodiversity (1992) (Article 8(j)). This changed the status of new accessions to the germplasm banks of members of the CGIAR. Accessions obtained after 1994 are subject to "prior informed consent" provisions and are held "in trust" to the countries that provide them, under the auspices of the FAO. The CGIAR has, as a policy decision, decided to treat all landraces it previously acquired in a similar fashion.

Despite years of international negotiations, exactly how "farmers' rights" will be internationally recognized in any tangible form remains unclear, except that the rights for international use have been allocated to the state from which the germplasm was contributed, rather than to the (in many cases, domestically politically oppressed) farmers who fostered development of the landrace germplasm. Examples of different views are represented in the IARC-oriented position of Swaminathan (1998), the Third World Network position (Nijar, 1998), and the compromise legislation proposed in Thailand (Lianchamroon, 1998).

One creative initiative is the Genetic Resources Recognition Fund at the University of California, Davis, which was established in 1996. The goals of this fund are: "(i) to establish a mechanism to recognize and compensate for germplasm contributions from developing nations; (ii) to provide a means for scientists to patent their inventions while maintaining productive collaborations and good relations with scientists from developing countries; (iii) to encourage university/developing nation/industry links for commercialization of genetically engineered products; (iv) to create a constructive solution that would be easy to implement and widely accepted; and (v) to create economic incentives for continued sharing of germplasm and conservation efforts" (Ronald, 1998).

The immediate purpose of the fund was to recognize the contributions of developing nations to the successful cloning of the *Xa21* gene, which confers resistance to bacterial blight in rice and to infections of the *Xanthomonas* species more generally in cereal crops. This achievement was the culmination of a truly multinational collaboration (Fischer and Barton, 1999). Dr. S. Devadath of the Central Rice Research Institute in Cuttack, India, identified an individual of the wild rice species from Mali, *O. longistaminata*, from the germplasm collection of Cuttack, with resistance to all tested isolates of the bacterial blight pathogen. Researchers at the International Rice Research Institute (IRRI) found resistance was due to a single locus, *Xa21*. Using the near-isogenic line IRBB21, obtained by back-crossing *O. longistaminata* to IR24, a cultivar produced at IRRI, as a recurrent parent, Ronald mapped the locus in 1990 at Cornell University where work on mapping the rice genome was supported by the Rockefeller Foundation. Further work at the University of California, Davis, and collaboration with the International Laboratory for Tropical Agricultural Biology in La Jolla, California, involving transformation of a Taiwanese cultivar to confer resistance, led to the location and coding of *Xa21*.

Royalties from the commercialization of *Xa21* will be used for fellowships to researchers from developing countries who will return to their homelands to continue their work. Preference will be given to students from Mali. The fund has raised more than US $150,000 in committed contributions. It is hoped that royalties from other patents based on research using landraces will be paid into this fund, with similar preferences to students from the country of origin.

5 IPR PROLIFERATION: THE DOWNSIDE

Patents and other means of IPR protection create the strongest incentive to research when there are no prior intellectual property claims on the research results. The complementary effect of prior non-patented research often enhances the value of first-round claims. In effect, the patentee captures value that previous research created. As patents on research tools and products proliferate, the restrictive force of the monopoly conferred by prior patents comes to bear on the next generation of research. Part of this is a natural re-scaling as patent rewards are prevented from reaping the full benefits of a free ride on prior public and private research (Koo, 1998). US hybrid corn companies, for example, no longer have elite publicly developed inbred lines available for use as parents of their commercial cultivars.

In addition to the cost of the rent transfer to prior patent holders, the costs of actually consummating licensing deals may be significant. These include the costs of discovering the existence, nature and ownership of prior claims, including those not yet published. They also include the costs of negotiating rights to use or acquire the relevant intellectual property in a dynamic market where the number of negotiating parties may be small, and values are not clearly established and are constantly changing. As patenting activity progresses in biotechnology, the number of separate rights needed to produce a new innovation proliferates. If, as has typically been the case, ownership of these rights is diffuse and uncertain, the multilateral bargaining problem can become difficult if not impossible to resolve. This is the "Tragedy of the Anticommons" noted by Heller and Eisenberg (1998).

The kind of diversified, independent innovation characteristic of non-profit research and educational institutions that is in many ways very effective can result in a balkanization of competing claims that can seriously impede subsequent innovation. Indeed, many participants report that public universities are especially difficult to deal with because of the inexperience of their negotiators and the constraints on the types of deals that can be made. For example, in the US, a university often cannot trade access to one research tool for access to another as easily as a private corporation. The university, unlike most corporations, typically has rules that oblige it to award a fraction of the value of the invention to employee-innovators, and this value is necessarily established by financial payments rather than exchanges of access rights, since values for calculation of awards need to be verified by actual financial transactions.

Within the corporate sector, the high costs of transactions in intellectual property are being "solved" by the rapid consolidation of biotechnology suppliers, and the further consolidation of these with plant breeders, seed distributors and chemical producers (Wright, 1999). Between 1995 and 1998, the pace of this concentration in the farm input markets was rapid in Europe and the US. Recently, the concentrated agriculture-related activities of these conglomerates are being separated from the more profitable pharmaceutical activities.

When the necessary rights are held in few hands, bargaining for access becomes more feasible. But even within the private sector, disputes over rights to dynamically evolving technologies have been fierce and extremely costly. Lerner (1995) reports that for every 100 US biotechnology patents, there are six patent suits, an extremely high figure relative to other areas of technology. In the case of one of the earliest applications, the use of *Bacillus thuringiensis* (*Bt*) genes in the transformation of corn, Barton (1998) lists at least 26 US disputes involving *Bt* as of May, 1997. I conjecture that, on average, each case that went to trial incurred at least several million dollars of costs to the parties involved, apart from the cost to the judicial system and the cost of complying with the final judgment or with conditions of settlement.[2] The willingness of all parties to expend such sums signifies genuine disagreement about the validity, value, and/or allocation of patent rights reveals the pervasive uncertainty of the innovation environment. But these expenditures are also becoming an effective barrier to entry and an incentive for further consolidation in the private sector. They are beyond the financial capacity of most non-profit research institutions, and most startup private ventures.

When negotiating with the private sector for access to technology, non-profits may face a problem worse than the challenge of multilateral bargaining – a refusal to bargain at all. This situation arose, for example, at my own university. University of California researchers, with some financial support from the state and from a tomato producers' organization, engaged in a project to develop a new tomato variety genetically engineered to express the endoglucenase gene so as to retard softening and enhance shelf

[2] Lerner (1995) estimates that patent litigation in the US Patent Office and the federal courts initiated in the year 1991 will lead to total legal expenditures of 1 billion 1991 US dollars, compared to $3.7 billion spending by firms on basic research in that year. Note that the figure excludes litigation in state courts.

life. The germplasm used in this transformation was another tomato variety developed with public support. A single private corporation was granted a patent for a key genetic element, a promoter, after the research began. This corporation refused to grant or bargain for commercialization rights. The whole research and development project was abandoned.

This experience is by no means unique. For example, CLIMA, an Australian organization, obtained permission from AgrEvo/PGS to use the bar gene in the transformation of a lupin cultivar to impart tolerance to the herbicide glufosinate, marketed as Liberty. After successful completion of this project, CLIMA sought permission to commercialize the transgenic cultivar, but AgrEvo/PGS refused to negotiate a license (Lindner, 1999).

A very serious consequence of this kind of experience is that researchers (and their funders) become wary of committing long-term research resources to areas where there is some probability that IPR problems will block utilization of the results. In the case of the California tomato research, cited above, it was reported that the tomato producers decided to discontinue support for university development of transgenic cultivars.

Much of the university discussion on intellectual property protection focuses on the disruption of patterns of intellectual communication essential to the function of the institution. Some expressions of concern along these lines assume a level of free communication of unpatentable knowledge at odds with my own experiences with other economists, despite the fact that we share a profession not famous for its patentable output. Sharing truly original ideas before claims to authorship are established (for example, via distribution of a working paper) occurs, if at all, principally among trusted colleagues. I suspect that many, if not most, potentially fruitful collaborative opportunities (including collaborations between economists in universities and their counterparts in IARCs) are lost due to the lack of clearly established rights to credit for ideas. Yet the publication of new ideas and imaginative applications continues apace, encouraged by the rewards of promotion, tenure and the respect of one's peers.

Related concerns are publication delays due to IPR concerns, as well as an embargo on public presentations to comply with patenting requirements. Since patents very likely speed up the development of ideas, the net effect on publicity may nevertheless be positive relative to the slower progress of ideas if there were no IPRs, especially under the European system of publication within eighteen months of filing.

With respect to the recognition of farmers' rights, their implementation is notable mostly by its lack of progress. Despite initial optimism regarding the commercial value of biodiversity *in situ*, current usage of landrace germplasm by crop breeders is low in most commercially important crops (Kate, 1995; Wright, 1998a). For new or minor crops, landraces are used more commonly. But when they are used, widespread abuse of UPOV rules is alleged to have occurred (RAFI, 1998), allowing landraces to be protected as if they were new, distinct cultivars. Problems identified include lack of trials to establish distinctiveness relative to germplasm source, no proof of breeding and abuse of provisional protection. Many cases of alleged abuse related to Australia which has been exemplary in providing access to relevant information. In one prominent example, an attempt by a West Australian government organization to obtain Australian plant variety protection for two chickpea cultivars, obtained from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India, resulted in an international outcry that led to a reversal of the organization's plans, and eventually to a tightening of Australian policy (RAFI, 1998; RAFI/HSCA, 1998).

Frustration over the free use of farmer-developed germplasm for the commercial development of private technology is not restricted to farmers in the South. In California, public-sector breeders have developed rice varieties through efforts supported partly by self-imposed assessments on rice production. New cultivars are distributed to producers at around the cost of production. Recently, a major agricultural biotechnology corporation used germplasm developed in this way as the basis for a transgenic cultivar incorporating its proprietary herbicide-tolerance gene designed to complement the use of its own patented herbicide (Wright, 1998b). If the producers had obtained a PVPC on their cultivar under the US Plant Variety Protection Act as amended in 1994, perhaps they would have had a claim on the transgenic germplasm as an "essentially derived variety" covered by the PVPC, although the scope of this "essentially derived" characterization has yet to be established. Given the very large sums that biotechnology firms have paid to owners of germplasm in the (admittedly far more lucrative) market for seed corn, it is possible that farmers would be offered a better deal on the transgenic crop if they owned the base germplasm. On the other hand, maybe the transgenic rice would not have been developed at all. To date, I know of no case in which the assertion of farmers' rights over agricultural crops has led to large transfers to those farmers or their governments. But it has, very likely, led to some reduction in the use of landrace germplasm in creating new cultivars of new or minor crops for use by farmers worldwide. This is hardly a win-win outcome.

At the moment, access to germplasm owned by corporations with IPR protection may be a far larger problem for breeders than the recognition of farmers' rights. Price (1999) reports the results of a survey of public plant breeding at 21 universities working in 41 crops in the US. Of 86 respondents, 48 percent indicated they were "having difficulties obtaining genetic stocks from companies". For 45 percent, this had interfered with their research, and for 28 percent it had interfered with their "ability to release new varieties". A further 23 percent reported that these difficulties interfered with the training of graduate students.

Even the admirable initiative to share some of the benefits of the patent on the *Xa21* gene for bacterial blight resistance with citizens of Mali, the source of the crucial germplasm, has its downside. The IPRs rest with the University of California. Genetic transformation has major advantages over traditional breeding when it comes to introducing the gene into germplasm adapted to complex rainfed rice environments. But a rice breeder in India, or at IRRI, would need to negotiate with the University of California for the right to use *Xa21* in such a transformation for the development of a new cultivar for release in India or Mali. The transaction costs involved could discourage or prevent such innovation. They also tend to leave the impression that, relative to the University of California, the institutions in India and in the Philippines that contributed to the development of the technology have not equally benefited.

6 STRATEGIC IMPLICATIONS: MAKE COMMON CAUSE WITH OTHER NON-PROFITS IN THE BROADER POLICY DEBATE

The challenges posed by proprietary claims for international collaboration in biotechnology are not unique to agricultural applications, and they will take time to resolve. Access to innovations useful in biotechnology is an issue shared by all other researchers in this general field, while the problem posed by "farmers' rights" is similar in nature (but not in degree) to that faced by pharmaceutical researchers interested in access to biodiversity products. The two problems require different approaches.

Access to research tools is a burning issue at the heart of non-profit biotechnology research in the US, the world leader in this area. Public funding of biotechnology in the US is dominated by the National Institutes of Health (NIH). International agricultural researchers might find the Report of the NIH Working Group on Research Tools instructive, if not dismaying (NIH, 1998). The Report notes that "although competitive pressures have always given scientists an incentive to withhold new research tools from their rivals, past practices allowed for relatively free exchange, typically without formal agreements and without explicit consideration of commercial rights or potential financial benefits.... It seems to be increasingly common, however, for the terms of these agreements to interfere with the widespread dissemination of research tools among scientists, either because owners and users are unable to reach agreement on fair terms or because the negotiations are difficult and cause protracted delays" (NIH 1998, p. 1f.). The Summary of Problems includes, among others, the following observations, which might be familiar to some international agricultural researchers:

- "The value of research tools is difficult to assess and varies greatly from one tool to the next and from one use to the next. Providers and users are likely to differ in their assessments of the value of research tools.
- Case by case negotiations for permission to use research tools and materials create significant administrative burdens that delay research.
- Institutions that seek to retain a competitive advantage from their proprietary research tools are generally unwilling to make them freely available. In order to minimize risks of competitive harm, they may seek to limit who has access to the tools, restrict how they are used, and restrict or delay disclosure of research results.
- Differences in the nature and value of research tools and differences in the missions and constraints of owners and users of research tools make it difficult and perhaps undesirable to standardize terms of access to research tools across the broad spectrum of biomedical research" (NIH 1998, p. 1f.).

The NIH recommends the free dissemination of research tools where possible, the use of the Uniform Biological Materials Transfer Agreement (UBMTA), and the development of guidelines for reasonable terms of licenses and material transfer agreements (MTAs). It is clear that biotechnology's intellectual property transactions will be far from solved by these initiatives, even when all parties are domestic and share NIH funding.

Two members of the working group concluded that "the research and commercialization issues…arise as much from the way in which standards of patent law have been applied in the biotechnology area as they do from the terms of MTAs and license agreements" (NIH 1998, p. 2; p. 28). They argued for an analysis of patenting issues, including standards of non-obviousness, the appropriate scope of claims, the utility requirement and the research exemption. I believe many economists familiar with the current US situation would agree.

Concerns similar to those expressed by the NIH are shared by the Board on Science, Technology and Economic Policy of the National Research Council. In its summary of an ongoing project on "Intellectual Property in the Knowledge-Based Economy", it notes that "…there is a growing friction over the assertion and exercise of some IPRs and claims that in some circumstances they may be discouraging research, its communication, and use. The question arises whether in some respects the extension of IPRs has proceeded too far" (National Research Council, Board on Science, Technology, and Economic Policy, 1999, p. 1).

There is a worldwide perception of the leadership of the US in setting the pace for the evolution of IPRs. However the extent of dissatisfaction with the current operation of the patent system within the community of economists, lawyers and research scientists in that country is not adequately understood elsewhere. Clearly international research institutions have an interest in following the current debate in the US and Europe. They are probably incapable of influencing the general evolution of IPRs, but they can press for the inclusion of the interests of international non-profit research collaborations in measures designed to address the interests of domestic research institutions in the leading countries, including the European Union and the US. The CGIAR and the FAO are well placed to coordinate such advocacy.

With respect to farmers' rights, it is obviously necessary to insist on full compliance with UPOV by those WTO members who support the enforcement of the TRIPs agreement in LDCs. Support should also be given to initiatives for compensating the providers of landrace germplasm that do not merely shut down germplasm use with no gain to holders of farmers' rights. But most of all, it is vital to ensure that the farmers' rights advocates have a realistic view of the prospective magnitude of rents available from private-sector seed producers. This point might be easier to make if all parties understand the current general lack of dependence of breeders of important commercial crops on recently acquired landraces (Wright, 1997).

Substantial private sector rents in corn and, to a lesser extent, in other crops, are produced by germplasm based on landraces that entered crop pedigrees generations ago. Arguments for significant international compensation based on "farmers' rights" must be based on a moral rather than legal obligation of beneficiaries to reimburse those who helped create the basis of their business. In the case of food crops, most of the benefits accrue to consumers, not landowners or farmers or seed producers. For example, wheat yields have increased greatly over the past eighty years, yet adjusted for inflation, rents on wheat land have increased much less, if at all, in real value. There are no significant profits from wheat seed production. The world's wheat consumers (mainly in the South) have been the beneficiaries via lower food prices.

All parties should take care to avoid confusing the situation in crop breeding with that of pharmaceuticals, where the maximum potential gains from a big research "hit" are so much higher. Furthermore, even for pharmaceuticals, the potential value of biodiversity *in situ* is, in general, very modest (Simpson et al., 1996; Wright, 1998a).

7 TACTICAL IMPLICATIONS

Researchers in IARCs are already using a wide array of biotechnology in their work (Cohen et al., 1998). If IARCs and other international research collaborations are to continue to fulfill their mission, continued access to biotechnology is crucial. Yet how can they continue this support if the modern research tools that they need are covered by intellectual property claims? A one-size-fits-all solution is not feasible. As in the private sector, different situations will require different strategies. Let us consider some that have been used to handle this problem in other organizations.

7.1 License IARC-Germplasm to Pay for Access to Research Tools

The main valuable output of IARCs is germplasm and its associated production information. In corn seed breeding in the US, the biotechnology revolution has resulted in huge increases in the value of elite privately developed germplasm. Currently, IARCs disseminate both seeds and information *gratis*, a policy that maximizes efficiency of use unless complementary adaptive investment requires some protection. Charging what the market will bear is against current CGIAR policy for landraces. For other in-house technology, licensing that precludes use by poor farmers in LDCs is presumably unacceptable.

7.2 Market Segmentation of Rights to IARC-Technology

If IARCs want to serve their poorest clients at no cost, it might make sense to discriminate geographically in setting license fees. An IARC could license or sell rights to technology associated with a given crop (other than landraces and released cultivars) in developed countries in exchange for needed proprietary technology. The IARCs could retain rights to distribute it freely for use in developing countries or for financial support, consistent with its stated mission to focus on the world's poor. But such segmentation appears to be against current CGIAR policy and would likely be opposed by developed-country donors who hope to continue to share in relevant research output. See Pardey et al. (1996) for an analysis of the value of wheat research benefits to the US.

7.3 Obtain Research Tools for Research Only

For scientists, it might be attractive to obtain research tools under licenses or other agreements limiting use to research only, as it allows them to pursue their projects using state-of-the-art technology. The NIH report referenced above urges for the provision of such licenses *gratis*, and indeed such licenses may often be available. Furthermore, a research license might generate externalities to the licensee in the form of learning-by-doing, and more generally, the development of intangible research capacities.

But a research license can make a research tool the cuckoo's egg of technology transfer. If the project succeeds, then the bargaining for permission to commercialize (or release to users at no cost) the fruits of the research effort must begin. The fact that the researchers have already incurred the "sunk cost" of all the research expenditures places them in a highly disadvantageous bargaining position. On the other hand, the holder of the IPR, even if he refuses to allow commercialization, gains valuable information about a potential product that he can use for his own purposes. If the research licensees have not claimed IPR on their output, the licensor might be able to appropriate much of the value of the research output in his own operation.

In some circumstances the situation might be more favorable to the licensee. If disseminating successful innovations based on proprietary technology to users in certain markets offers little commercial benefit, a private licensor might be persuaded to license such dissemination *gratis* if he sees some kind of benefit (for example, enhanced public image) from doing so. This is discussed further below.

7.4 Cross-Licensing

This is a popular solution for deals among biotech oligopolists. Rather than bargain over the values of individual innovations, firms exchange rights to a set of patents, with or without compensatory payments (Grindley and Teece, 1997; Hall and Ham, 1999). Public institutions also find that their ownership of patents can greatly facilitate private-sector collaboration.

The experience of the Cooperative Research Centers (CRC) Program in Australia is typical and instructive: "We discovered that research capacity alone was not enough. Research concepts and unpublished data were sometimes interesting for our Industry Associates, but developing collaborative projects based on them was difficult. The breakthrough came when the CRC for Plant Science started to take out patents. Patents are property; property is valuable (or so prevailing wisdom then suggested), and therefore it can be traded. It was as if we had suddenly, almost magically, acquired a stack of chips and could get our feet under the card table. It was then that the tactic of progressive engagement started to pay off' (Buller and Taylor, 1999).

In universities, cross-licensing is often precluded since its contracts require compensation for university innovators (see above). In other institutions, including IARCs, this might not be the case. However, at CGIAR Centers, licensing would have to be restricted to property other than landraces they have received and other than the breeding materials they distribute to NARSs and others, which they are committed to furnish without charge to the world at large. Despite these severe constraints, candidates for cross-licensing have already been nominated. The near-isogenic lines of rice germplasm at IRRI, such as the material used in the discovery of *Xa21* discussed above, are examples of proprietary technology that might be licensed via an MTA.[3] Fischer and Barton (1999) propose an MTA that offers such material at no cost in exchange for access to information about subsequent discoveries (after a lag to allow applications for patents), and zero-cost, non-exclusive research licenses to IARCs of the CGIAR and NARSs in LDCs. Furthermore, they propose that a non-exclusive license for commercialization shall be granted to the research centers at a reasonable royalty and at zero cost for subsistence agriculture and other uses not in competition with the private sector.

7.5 Persuade IPR Holder to License Technology Gratis

Beyond wheat, maize, some kinds of rice, soybeans and barley, private (and public) IPR holders might be persuaded to allow IARCs and NARSs in developing countries to use proprietary biotechnology without any direct compensation because there is obviously such little risk to the significant commercial markets that are the focus of the IPR holders' hopes for profits (i.e., low opportunity costs for the IPR holder). Other crops of interest to NARSs include foods that are necessities for poor consumers; they have low income elasticities of demand. Their markets will not become much more attractive commercially if and when poor consumers' incomes increase. Rather, they will substitute more desirable foods, including wheat and meat, as their incomes grow.

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[3] As described in Barton and Siebeck (1994, p. 11f.), "...MTAs are contractual agreements concluded between two or more parties. As contracts they enjoy the protection of the law in many nations: failure to perform what is promised is a breach of contract which gives one party the right to bring action against the other party, such as suing for damages. Unlike patents or copyrights, MTAs do not rest upon codified legal statutes defining specific rights and obligations. Instead, reflecting freedom of contract, parties to a MTA have wide discretion in setting the terms of their agreement and tailoring them to their specific needs."

Already, we have a few cases of technology transfer without charge in these non-commercial crops. Monsanto has made its technology available to achieve virus resistance in several non-commercial potato cultivars popular among the poor in Mexico (Qaim, 1999). It has also supported the incorporation of virus resistance technology in sweetpotato in Africa. Such collaboration might become increasingly attractive to corporations as international opposition to corporations that market transgenic seeds gathers steam. Technology that helps solve the nutritional deficiencies or health problems of poor consumers could generate especially desirable publicity. This type of collaboration might be feasible for most other CGIAR crops, especially if the IARCs have the capacity to use the technology with little assistance from the commercial provider. It might also be very important for the potential corporate donors that ways be found to protect the commercial provider from blame or liability for misuse of their technology. IARCs must in turn assess the appropriateness of the technology for their organizations. For example, the CGIAR decided against the adoption of "terminator" technology that prevents seed saving for replanting (Mittal and Rosset, 1999). Monsanto abandoned commercialization of the technology in October 1999 (Kaiser, 1999).

7.6 Direct Programmatic Research Support from the Private Sector

Rather than operate in the piecemeal approach to technology transfer described above, for-profit corporations might be persuaded to give more general support to international agricultural research collaboration. Important examples of such support from corporations with significant market power have already been observed. Merck, the huge pharmaceutical corporation, has supported a public database of genome markers called single-nucleotide polymorphisms (SNPs), in preference to partaking in a competing private-sector initiative (Marshall, 1998a). The motivation for this type of expenditure, which does not appear to be conditioned on any claim to property rights, is not clear. But it indicates that the private sector might, on occasion, choose to support public over private research initiatives in areas related to its own endeavors.

Another example is the involvement of a foundation funded by Novartis, a multinational life-science corporation, in the support of plant biology research at the College of Natural Resources at the University of California, Berkeley (Rausser, 1999). This support is conditioned on the right to be the first to negotiate the rights to (as distinct from right of first refusal to) innovations arising out of research in plant biology that is supported by the donor, and the donor also has rights to appoint a minority of the board that directs research funded by the Foundation (Mena and Sanders, 1998). But the conditions seem surprisingly moderate, given the five-year commitment at US $5 million per year. Knowledgeable observers conjecture that a major portion of the return envisaged by Novartis consists of the benefits of intimate access to the intellectual resources of the Berkeley campus.

A third example, also related to my academic home, is Monsanto's donation of technology for transformation of corn by *Agrobacterium* technology to the University of California. As part of a divestiture of assets ordered by the Justice Department as a condition for acquisition of DeKalb, the seed producer, Monsanto was required to relinquish patents it held or one of two means of transformation. Rather than sell to a competitor, Monsanto, under extreme time pressure, gave it to the University, which I understand is free to license access to the technology to third parties.

These three examples show that it is conceivable that corporations would be willing to exchange access to technology for close contacts with the innovative activities and expertise of IARCs, without making any demands for proprietary rights to the output. IARCs should consider means of making this kind of transfer easy for the private sector, while clearly establishing the continued independence of their research mission from undue private-sector influence.

7.7 Organize a Boycott Against "Hold-Up" by IPR Holders

Lesser (1999) explored the option to organize a public collaborative boycott against companies involved in ex post "hold-ups", such as the opportunistic exploitation of successful research licensees by the licensor. This tactic appears to have been used with some effect by NIH in a protracted struggle with DuPont over the terms of research licensing for mice genetically engineered with the patented "cre-lox" system (Marshall, 1998b). Significantly, the compromise excluded not only commercial use but also "any activity associated with higher plants or agricultural applications" (NIH, 1999). Making common cause with more powerful allies (such as NIH) in applying pressure on holders of IPRs might help ensure that future concessions are extended to international agricultural (non-profit) research and non-profit dissemination to non-commercial markets. Another element of Lesser's creative initiative, sponsoring the creation of substitutes for blocked technology, is already being implemented on a modest scale.

7.8 Ally with Independent Developers of Research Tools

Allies willing to share their proprietary tools can be hard to find. Independent biotech research laboratories that develop such tools generally guard their IPRs as bargaining chips. The ultimate aim of many innovators is to attract venture capital support leading to the financial bonanza of a successful initial public offering; their IPR portfolio is key to achieving this goal.

There are exceptions to this rule. For example, the Center for the Application of Molecular Biology to International Agriculture (CAMBIA) in Australia aims to generate new research tools for developing-country agriculture that are unencumbered by restrictive proprietary claims. The magnitude of the enterprise has been limited by the amount of financial support, the sources of which include revenues from licensing previously developed biotechnology (notably the GUS marker) to developed-country corporations.

One of CAMBIA's initiatives is to develop interactive software to identify prior intellectual property claims and to help negotiate the international IPR minefield. This is an initiative that could make further international collaboration more feasible by mitigating the difficulties caused by uncertainty about prior claims to useful biotechnology. In another imaginative international collaborative initiative, the International Institute for Tropical Agriculture (IITA) in Nigeria recently chose CAMBIA as its biotechnology arm (Finkel, 1999).

7.9 Merge or Form Joint Ventures

Merging or forming a joint ventures with a private holder of necessary technology are prime private-sector solutions to minimize the private cost of transactions in IPRs used in research. It can also lead to the private benefits (and public costs) of monopoly. I assume it is not an option for IARCs. Monsanto is attempting to market transgenic cotton in China in a joint venture with a provincial public seed-producing organization, with mixed results (Pray, personal communication).

7.10 Use Tools Under IPR Laws of IARC Host Countries

In many cases, research tools and genetic material – especially plant cultivars – may not be covered by patents in the host countries of international centers. Even after complying with TRIPs, under the *sui generis* protection that many LDCs will adopt it may be legal for the IARCs to breed new cultivars using cultivars patented in developed countries. These varieties might not be exportable to developed countries, but most CGIAR crops have no significant exports to developed countries (Binenbaum and Wright, 1998). Hence the new world of the WTO might facilitate a kind of indirect market segmentation, in which LDCs get the new technology for free and proprietary claims are enforced in developed countries. Furthermore, cultivars incorporating genes patented in LDCs that have adopted TRIPs may not be subject to effective intellectual property claims if those countries have neither the legal means nor the will to enforce them. IARCs might consider arranging for their NARS collaborators to take responsibility for domestic intellectual property claims.

However, if this approach is adopted without the assent of IPR holders, the costs could be high in some cases. This might include the loss of fruitful collaborations with the same entities in other areas and the possible loss of support from developed-country donors. If biotechnology innovations or products incorporating such biotechnology are exported to countries where patents on the innovations are enforced, the prospect of ruinously costly litigation must also be considered.

8 CONCLUSION

The revolution in biotechnology has opened up new avenues for international agricultural biotechnology. But the international proliferation of proprietary claims on that technology heightens concerns about access for international and national agricultural research centers. The structure of these institutions places them at a disadvantage, in terms of resources and expertise, in the kind of bargaining over proprietary rights that occurs between for-profit corporations. For such institutions, professional assistance in handling IPRs will be a continuing need. The CGIAR decision to establish a modest advisory capacity at the International Service for National Agricultural Research (ISNAR) is a positive development. The CAMBIA strategies for helping researchers avoid traps caused by blocking technologies exemplify positive initiatives that deserve attention and support.

It is important to realize that many of the transaction problems in biotechnology IPRs are shared by the large human health research complex. International agricultural research, including IARCs and interested non-government organizations, should try to inject their interests in the broader discussion of these issues, both in research leaders like the US and the European Union, and in less-developed economies where laws regarding IPRs are being revised. Contractual innovations in other areas of biotechnology transfer should be followed closely. Efforts should be made to turn the particular contracting disadvantages of IARCs into opportunities for success in developing alternative forms of technology transfer.

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REFERENCES

Alston, J.M., P.G. Pardey, and V.H. Smith (eds.) (1999): *Paying for Agricultural Productivity*. Johns Hopkins University Press, Baltimore.

Barton, J.H. (1998): The Impact of Contemporary Patent Law on Plant Biotechnology Research. In: S.A. Eberhard, H.L. Shands, W. Collins, and R.L. Lower (eds.). *Intellectual Property Rights III; Global Genetic Resources: Access and Property Rights*. Crop Science Society of America, Madison, pp. 85–97.

Barton, J.H., and W.E. Siebeck (1994): Material Transfer Agreements in Genetic Resources Exchange—The Case of the International Agricultural Research Centres. Issues in Genetic Resources, No. 1, International Plant Genetic Resources Institute, Rome.

Binenbaum, E., and B.D. Wright (1998): On the Significance of South-North Trade in IARC Crops. A report prepared for the Expert Panel on Proprietary Science and Technology of the Consultative Group on International Agricultural Research, Washington, D.C.

Buller, C., and W. Taylor (1999): Partnerships Between Public and Private: The Experience of the Cooperative Research Center for Plant Science in Australia. *AgBioForum* 2 (1), pp. 17–23.

CGIAR (1998): Shaping the CGIAR's Future: Summary of Proceedings and Decision*s*. International Centers Week, 26-30 October, Consultative Group on International Agricultural Research, Washington, D.C. pp. 52–53.

Cohen, J.I., C. Falconi, J. Komen, and M. Blakeney (1998): Proprietary Biotechnology Inputs and International Agricultural Research. ISNAR Briefing Paper, No. 39, International Service for National Agricultural Research, The Hague.

Contracting Parties to the GATT Uruguay Round (1994): Annex IC: Agreement on Trade-Related Aspects of Intellectual Property Rights, Including Trade in Counterfeit Goods. World Trade Agreement, General Agreement on Tariffs and Trade, Marrakesh.

Enriquez, J. (1998): Genomics and the World's Economy. *Science* 281, pp. 925–926.

FAO (1983): International Undertaking on Plant Genetic Resources. 22nd Conference, Food and Agriculture Organization of the United Nations, Rome.

Finkel, E. (1999): Australian Center Develops Tools for Developing World. *Science* 285, pp. 1481–1483.

Fischer, K.S., and J.H. Barton (1999): Gene Discovery in Rice: The Exchange of IRRI's Biological Assets. Draft of a discussion paper, Stanford Law School, Stanford.

Ghijsen, H. (1998): Plant Variety Protection in a Developing and Demanding World. *Biotechnology and Development Monitor* 36, pp. 3–5.

Grindley, P.C., and D.J. Teece (1997): Managing Intellectual Capital: Licensing and Cross-Licensing in Semiconductors and Electronics. *California Management Review* 39 (2), pp. 8–41.

Hall, B.H., and R.M. Ham (1999): The Patent Paradox Revisited: Determinants of Patenting in the U.S. Semiconductor Industry, 1980-94. Mimeo., Department of Economics, University of California, Berkeley.

Heller, M.A., and R.S. Eisenberg (1998): Can Patents Deter Innovation? The Anticommons in Biomedical Research. *Science* 280, pp. 698–701.

Huffman, W.E., and R.E. Evenson (1993): *Science for Agriculture: A Long-Term Perspective*. Iowa State University Press, Ames.

Juma, C. (1989): *The Gene Hunters: Biotechnology and the Scramble for Seeds*. Research Series No. 1, African Centre for Technology Studies, Princeton University Press, Princeton.

Kaiser, E. (1999): Monsanto Vows not to Develop 'Terminator' Gene. Reuters, 4 October, Chicago.

Kate, K. (1995): Biodiversity Prospecting Partnerships: The Role of Providers, Collectors and Users. *Biotechnology and Development Monitor* 25, pp. 16–21.

Koo, B. (1998): The Economics of Plant Genetic Resources: The Effects of Alternative Intellectual Property Protection Systems and Advances in Biotechnology. Unpublished Ph.D. dissertation, Department of Agricultural and Resource Economics, University of California, Berkeley.

Lehne, R., and G. van Roozendaal (1995): U.S. Government Role in Biotechnology. *Biotechnology and Development Monitor* 24, pp. 6–8.

Lerner, J. (1995): Patenting in the Shadow of Competitors. *Journal of Law and Economics* 38 (October), pp. 463–495.

Leskien, D. (1998): The European Directive on Biotechnology. *Biotechnology and Development Monitor* 36, pp. 16–19.

Lesser, W. (1999): 'Holding Up' the Public Agbiotech Research Sector Over Component Technologies. Presentation at the conference "Transitions in Agbiotech: Economics of Strategy and Policy", Washington, D.C.

Lianchamroon, W. (1998): Community Rights and Farmers' Rights in Thailand. *Biotechnology and Development Monitor* 36, pp. 9–11.

Lindner, R. (1999): Prospects for Public Plant Breeding in a Small Country. Paper presented at the conference "The Shape of the Coming Agricultural Biotechnology Transformation", 17-19 June, Tor Vergata University, Rome.

Marshall, E. (1998a): Private Help for a Public Database? *Science* 280, pp. 667–668.

Marshall, E. (1998b): NIH, DuPont Declare Truce in Mouse War. *Science* 281, pp. 1261-1262.

Mena, J., and R. Sanders (1998): Swiss Pharmaceutical Company Novartis Commits $25 million to Support Biotechnology Research at UC Berkeley. Public Affairs News Release, 11/23/98, University of California, Berkeley.

Mittal, A., and P. Rosset (1999): Seeds Sow Controversy. *San Francisco Chronicle*, 1 March, p. A21.

National Research Council, Board on Science, Technology, and Economic Policy (1999): Excerpt from Summary Sheet (dated 8/16/99). Conference "Intellectual Property in the Knowledge-Based Economy" held 19 October, University of California, Berkeley.

NIH (1998): Report of the National Institutes of Health Working Group on Research Tools. Draft presented to the Advisory Committee to the Director, 4 June, National Institutes of Health, Bethesda, MD.

NIH (1999): Memorandum of Understanding: DuPont Pharmaceuticals Company and Public Health Service, United States Department of Heath and Human Services, July 1998. National Institutes of Health, retrieved from the internet: www.nih.gov/od/ott/cre-lox.htm.

Nijar, G.S. (1998): Community Intellectual Rights Protect Indigenous Knowledge. *Biotechnology and Development Monitor* 36, pp. 11–12.

Pardey, P.G., J.M. Alston, J.E. Christian, and S. Fan (1996): Hidden Harvest: U.S. Benefits from International Research Aid. Food Policy Report (September), International Food Policy Research Institute, Washington, D.C.

Powledge, F. (1995): Who Owns Rice and Beans? Patents on Plant Germplasm. *Bioscience* 45 (7), pp. 440–445.

Price, S.C. (1999): Public and Private Plant Breeding. *Nature Biotechnology* 17 (10), p. 938.

Qaim, M. (1999): Modern Biotechnology for Small-Scale Farmers in Developing Countries: Contradiction or Promising Option? Paper presented at the conference "The Shape of the Coming Agricultural Biotechnology Transformation", 17-19 June, Tor Vergata University, Rome.

RAFI (1998): Plant Breeders' Wrongs Righted in Australia? RAFI News Release, 10 November, Rural Advancement Foundation International, Winnipeg.

RAFI (1994): Conserving Indigenous Knowledge. Rural Advancement Foundation International, United Nations Development Program, New York.

RAFI/HSCA (1998): Plant Breeders Wrongs: An Inquiry into the Potential for Plant Piracy through International Intellectual Property Conventions. Rural

Advancement Foundation International, Heritage Seed Curators Australia, Winnipeg.

Rausser, G. (1999): Public/Private Alliances. *AgBioForum* 2 (1), pp. 5–10.

Ronald, P.C. (1998): Genetic Resource Recognition Fund. *AgBiotech News and Information* 10 (1), pp. 19N-21N.

Simpson, R.D., R. Sedjo, and J. Reid (1996): Valuing Biodiversity for Use in Pharmaceutical Research. *Journal of Political Economy* 104, pp. 163–185.

Swaminathan, M.S. (1998): Farmers' Rights and Plant Genetic Resources. *Biotechnology and Development Monitor* 36, pp. 6–9.

Weiss, R. (1999): Seeds of Discord. Monsanto's Gene Police Raise Alarm on Farmers' Rights, Rural Tradition. *Washington Post*, 3 February, p. A01.

van Wijk, J. (1995): Plant Breeders' Rights Create Winners and Losers. *Biotechnology and Development Monitor* 23, pp. 15–19.

Wright, B.D. (1999): Challenges for Public Agricultural Research and Extension in a World of Proprietary Science and Technology. Mimeo., Department of Agricultural and Resource Economics, University of California, Berkeley.

Wright, B.D. (1998a): Valuing Farmers' Rights. In: R.E. Evenson, D. Gollin and V. Santaniello (eds.). *Agricultural Values of Plant Genetic Resources*. CAB International, Wallingford, UK, pp. 219–232.

Wright, B.D. (1998b): Public Germplasm Development at a Crossroads: Biotechnology and Intellectual Property. *California Agriculture* 52 (6), pp. 8–13.

Wright, B.D. (1997): Crop Genetic Resource Policy: The Role of Ex Situ Genebanks. *Australian Journal of Agricultural and Resource Economics* 41 (1), pp. 81–115.

PART V

THE ROLE OF DIFFERENT PLAYERS

OVERVIEW

Robert W. Herdt

This last part of the book highlights the different contributions that private companies, the international public sector, and the national public-sector research organizations can make to help the poor through agricultural biotechnology.

All human enterprises are motivated by a complex combination of incentives and constraints. Fame, power, prestige, money, loyalty, love and selflessness motivate individuals – as do fear, poverty and threats of violence. Organizations provide the context within which most individuals do their work, and these groups provide other motivations, such as corporate profit, power and longevity. Furthermore, the appropriate roles of organizations are understood to be quite different: the state enforces the "rules of the game", companies employ resources to make profits, public-sector research generates knowledge available to all, donors provide funds and national organizations adapt general advances to their countries' specific needs.

It is therefore a challenge for representatives from four different types of organizations – private companies, international agricultural research centers, national agricultural research systems (NARSs), and development assistance agencies – to report about their respective role in "Providing Biotechnology Access to the Poor". The effort seems to imply that each organization has some responsibility to provide such access to the poor, and

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indeed, the authors seem to have accepted that assumption in their discussions.

As their mission statements testify, the Consultative Group on International Agricultural Research (CGIAR) and the World Bank have both clearly accepted their responsibility for improving the lives of the poor. But it is more difficult to understand, on the face of it, why private companies would take that view. Of course, one can see obvious differences in the extent to which different companies accept such a role. All the actors, however, are operating within a context where the "rules of the game" regarding biotechnology recently seem to have changed dramatically. There are challenges to what seems to be the dominant interpretation of the rules.

The ability to patent genes and gene components and the discovery of novel DNA manipulation techniques that make it possible to identify any organism and its progeny with an extremely high degree of reliability, have led to new technologies that are being patented in some countries. The technologies enable the creation of organisms that express genes taken from other organisms that are very different. Some oppose the genetic engineering that leads to such organisms, and some oppose the patenting of techniques and materials used in such genetic engineering. Motivations may be ethical, social or economic. Others believe the technologies should be used to whatever end they can be used, following the same intellectual property rules applied to mechanical inventions.

Questions about the ethics, safety and value of plant biotechnology have made its proponents eager to put as positive a light on plant biotechnology as possible. One argument along these lines is that plant biotechnology will increase food production, farm efficiency and nutritional benefits for the world's poor. The authors of the papers in this section each make this case from their respective viewpoints.

Bernard Convent reports about the current role that large private-sector companies play and about the role they could play in the future. Although commercial farmers in middle-income countries are increasingly regarded as an interesting clientele by transnationals, Convent is more pessimistic about providing end-technologies to resource-poor subsistence farmers in the least-developed countries. He does see, however, a private-sector role in assisting with know-how and in making available certain intermediary and enabling technologies that can be used in public research dedicated to the poor. Donating such technology components to improve the quality of life in developing countries could enhance company profiles, especially in times when public acceptance of biotechnology is thin. Moreover, sharing technology can be in the best strategic interest of the private sector because those farmers who benefit from today's technology donations might well become tomorrow's commercial customers.

Michael Morris and *David Hoisington* give an overview of biotechnology activities in the 16 CGIAR Centers where molecular techniques are used in a needs-driven approach. Most of the Centers have already gained experience with biotechnology, and some have even built up significant expertise. Yet the authors claim that the CGIAR should pursue a clearer strategy to strengthen national regulatory frameworks in developing countries, and, as a credible international institution, that it should play a more important role in promoting public awareness of biotechnology. Morris and Hoisington also discuss the repercussions for the CGIAR of the increasing privatization of agricultural research. They conclude that if the Centers are to continue to pursue their mandate to serve the poor in developing countries, they will have to learn how to collaborate effectively with a much wider range of partners in an environment that will become increasingly market-driven. In addition, formulating a viable intellectual property rights policy at the institutional level remains a major challenge.

The biotechnology situation in different developing-country NARSs is analyzed in the chapter by *Willem Janssen et al.* Compared to most industrialized countries, the biotechnology capacity of developing countries is generally much lower. This is due primarily to a lack of human resources, budgetary limitations, unclear priorities and institutional constraints, such as deficient linkages between basic and applied research and with organizations from abroad. The authors propose different strategies to improve the role of NARSs in providing biotechnology access to the poor, but they stress that success will depend on how effectively biotechnology is integrated with traditional approaches of agricultural research and technology dissemination.

This part's last chapter, by *Gesa Horstkotte-Wesseler* and *Derek Byerlee*, deals with the role of development assistance agencies. Although many of these agencies have developed a biotechnology strategy, the overall donor contributions to biotechnology are small in relation to the challenges facing developing countries and in relation to private-sector research investments in industrialized countries. Hence, the impact on the poor, especially in regard to higher-end biotechnologies, is still rather limited. With few exceptions, the efforts of individual donors are fragmented and pay too little attention to exploiting the comparative advantage of the private sector. The authors conclude that more and better-coordinated donor support is urgently needed to mobilize the potential of agricultural biotechnology to benefit the poor. Such support, however, should not be at the expense of traditional research; instead, it should take the form of a concerted effort to sharply raise the total investment in agricultural research at the national and international levels.

These papers make clear that there can be no single "correct" approach to providing biotechnology access to the poor. Accordingly, against the background of the rapidly changing framework conditions in which science is carried out, a reorientation of tasks and mandates is surely required by all types of organizations. Innovative partnerships based on comparative advantages are needed within the public and the private sector – but especially also across these sectors. This requires improved communication systems to pool interests and resources and to share information. Only then will the efforts of both the public and private sectors most efficiently contribute to achieving the stated objectives. These papers take some initial steps in that direction.

Chapter 19

THE ROLE OF THE PRIVATE SECTOR IN PROVIDING BIOTECHNOLOGY ACCESS TO THE POOR

Bernard Convent

Abstract: The potential of biotechnology to benefit the poor in developing countries is large, and yet, due to economic/regulatory reasons, private-sector research efforts focus on a limited number of key global crops, neglecting many relevant crops and traits that are important to small-scale subsistence farmers. Although it is not within the goals of private companies to develop end-technologies for use in the least-developed countries, these companies could play a more important role in providing intermediary technologies. Certain minimum scientific and regulatory capacities are required to further allow the adaptation of these intermediary technologies to local needs, and in many cases, developing these capacities will require international public assistance. The only way forward is to strengthen private-public sector partnerships that focus on specific projects.

1 INTRODUCTION

For a number of years biotechnology has been profoundly changing the farming industry in many countries. However, although the potential benefits of biotechnology for developing countries are high, its application is largely concentrated in the industrialized world. Private companies make the overwhelming share of research investments, and they target their efforts to the large commercial markets of North America, Europe and some middle-income countries. This situation threatens to leave the poor even further behind. So who will provide appropriate biotechnologies to the poorest countries, those with low per capita incomes, high deficits in basic needs, insufficient infrastructure, low productivity in agriculture and large subsistence sectors? The present paper discusses whether private companies have a role to play here.

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Does biotechnology developed by the private sector meet the agricultural requirements of the poor? If we assume for the moment that certain technologies would do so to some extent, a second question arises: how can these proprietary technologies be further adapted so that resource-poor farmers can readily use them for their purposes?

In order to answer these questions, we first of all analyze the major current and future fields of private biotechnology research. We then discuss different possible situations for the transfer of proprietary technology and other related challenges.

2 PRIVATE-SECTOR RESEARCH DIRECTIONS

If we look at the crop biotechnology research situation in the private sector today, we see that it is concentrated on a limited number of activities. In terms of crop species, soybeans, maize, cotton, rapeseed and vegetables are the main targets of private biotechnology research. The first four crop species alone account for almost 100 percent of the global area cultivated with genetically modified organisms (cf. James, 1999). These are the four key global crops, which in the near future will be complemented by wheat and rice.

In terms of modified crop traits, herbicide tolerance and insect resistance dominate commercial biotechnology. Another available trait, male sterility, is of particular importance for breeders because it allows for the exploitation of hybrid vigor in crops that cannot be easily hybridized otherwise.

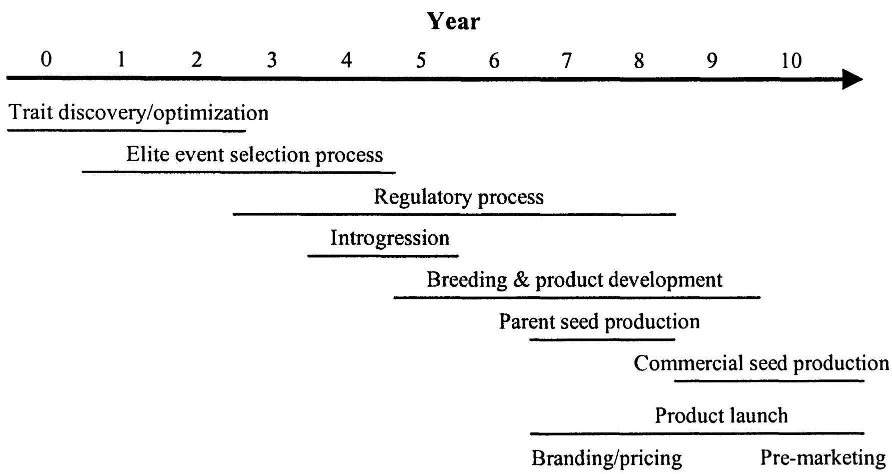
In the near future, a number of disease resistance traits will appear, and advances in functional genomics will also introduce more complex traits relating to crop quality (e.g., altered structures of fatty acids, proteins and carbohydrates in crops used as food, feed or as industrial raw products). Furthermore, the use of crops as bioreactors to produce specialty chemicals, such as pharmaceuticals or biodegradable plastics, will become possible with a better understanding of genetic functions and interlinkages.

Analyzing the distribution of transgenic field trials by crop trait provides an impression of the increasing importance of altered crop quality characteristics in biotechnology research. Recent data from the United States Department of Agriculture show that quality traits already account for almost 30 percent of all transgenic field trials in the USA (USDA/APHIS, 2000). Gene stacking (the design of crop varieties with several genetically modified traits) will also become more relevant in the future. Insect resistance and herbicide tolerance have already been stacked and commercialized in corn and cotton. Combinations of improved agronomic traits and altered quality characteristics will follow. Yet it must be stressed that the private sector is developing these technologies for a limited number of economically important crop species – the key global crops mentioned above.

This is because the huge investments associated with crop improvement research and product development can only be recuperated with sufficiently large marketing potentials. It is not a new phenomenon of biotechnology that the portfolio of private-sector target crops is rather narrow. But for biotechnology this phenomenon is even stronger because of the additional biosafety and foodsafety regulatory issues that prolong the time it takes to get a product out the door. Today, we estimate that the time required from trait discovery to the market launch of a new transgenic variety is at least 6 years, but in many cases this exceeds 10 years, depending on the regulatory requirements. These long time lags certainly lead to sharp cost increases. For instance, the average cost to develop an elite event (i.e., the transfer of a discovered trait into a so-called donor crop that can then be used to introgress the trait into different varieties), has escalated from around US $3 million a couple of years ago to $10 million today. Given the public biosafety and foodsafety concerns, there is every reason to expect that this cost will further rise in the near future.

To illustrate this, Figure 1 shows the gestation process of a transgenic crop variety with a newly discovered trait. The time profile is based on the rather optimistic case of a product launch in the USA. From trait discovery to possible product commercialization requires about 8 years. Apart from biosafety and foodsafety requirements, the development process also

Figure 1: Discovery and development process of a transgenic crop variety



involves intellectual property protection for the innovation. Of course, it must also not be forgotten that patent protection expires after a given length of time.

These illustrations provide some background to the priority list of crop species selected by private biotechnology research. Many of the species relevant for smallholder agriculture in developing countries are not included. In fact, there is little knowledge in the private sector relating to crops other than the key global crops. Furthermore, the problems faced by subsistence farmers in developing countries are not well understood by private corporations.

Consequently, developing countries today can only immediately benefit from private biotechnology research if they grow the key global crops. Of course, many countries do so. A good example is Argentina, which already grows several million hectares of transgenic crop varieties developed by private industry. But Argentina is comparatively advanced among developing countries, and Argentinean farms growing transgenic crops are predominantly large commercial entities. So far, modern biotechnology has hardly reached the small-scale farmers in developing countries. As I mentioned earlier, transgenic wheat and rice varieties will become available in the near future, which could improve the situation for the poor to some extent. But it remains to be seen how intellectual property rights (IPRs) problems can be settled so that small-scale farmers could use proprietary technologies.

There is no doubt that biotechnology holds great potential to increase global food production in a sustainable way. Indeed, population forecasts show that unless we exploit innovative technologies such as biotechnology we will not be able to produce enough food over the next generation. This global challenge, we believe, can be met. We are less optimistic, however, when it comes to the poorest countries, especially in Africa. Here, food demand in 2025 will probably exceed food supply substantially. And there is a limited role that biotechnology can play to meet those needs, since proprietary technologies do not exactly meet the specific requirements of these regions. If it already takes 10 years to develop a new transgenic crop variety in the USA or in Europe, the development time in Africa will be much longer due to lack of research, insufficient regulatory capacities and higher commercial risks.

3 TRANSFER OF PROPRIETARY TECHNOLOGY

In the previous section it became obvious that the private sector can play a limited role in providing appropriate biotechnologies to the poor. Now, does that mean that we have to lay down our arms and say we cannot contribute? Certainly not. This section explores the options available for transferring privately developed technologies for exploitation by subsistence farmers in developing countries. It does so by addressing the second major question posed in the introduction: How can proprietary technologies be further adapted so that resource-poor farmers can readily use them for their purposes? In doing so, we will review four situations under different framework conditions which, however, do not claim to be all encompassing.

1. *The private sector provides access to proprietary elite events.* This option presupposes that the crops grown in developing countries belong to the key global crops, such as maize, soybeans, cotton, rapeseed and certain vegetables. In this case the private sector could provide access to the existing deregulated elite events, expressing the proprietary technology. The underlying crop traits could then be introgressed into local varieties. When talking of deregulated elite events we mean that the regulatory process associated with biosafety and foodsafety has already been absolved and completed in a number of countries (e.g., USA, Australia, Europe and Japan). This is certainly the easiest way to transfer the technology because its deregulated status in a number of countries means that there will be little concern about further international movements. Also, dealing with available elite events does not presuppose sophisticated technology capacities in the recipient country, and the time needed to adapt the innovation to local requirements is comparatively short. However, there are basically three challenges that need to be resolved for efficient technology adaptation and use. First, an effective IPR regime must be in place because companies will only transfer patented technology if it is recognized as private property. Second, there must exist some minimum capacity to monitor the genetically modified organism, (i.e., the breeding sequence must be understood because otherwise the trait might get diluted or even completely lost). Third, the local seed industry must be able to ensure the effective multiplication and distribution of high quality seeds.
2. *The private sector provides access to the proprietary gene.* It is also possible to use genes encoding valuable traits that have been identified and isolated by private companies for crops not on the corporate sector priority list. *Bacillus thuringiensis* (*Bt*) genes that are used by the private sector, for instance, in maize and cotton could theoretically also be used

in cassava or other poor people's crops. Yet the challenges for this kind of technology transfer are much higher than those associated with the transfer of available elite events. In addition to the conditions mentioned under point (1), advanced biotechnology capacity is required because the incorporation of genes into new crop species can be a fairly complex and protracted process. New transformation and regeneration protocols have to be developed, which can require considerable research investments. It is also important for the technology package to meet international safety standards, because dealing with the poor should not be a reason to relax these standards. International biosafety and foodsafety experiences might help to establish national guidelines, but it is important to consider that the ecological conditions in the tropics and subtropics are different from those in the temperate climates of most industrialized countries.

3. *The private sector provides access to proprietary enabling technology.* Enabling technologies, such as certain transformation procedures or promoter and marker genes, are theoretically applicable to all crop species, so developing countries could use them to express desirable agronomic or quality traits in their own priority crops. However, once again the necessary absorptive capacity increases. Similar to what was mentioned under point (2), experience with both molecular biology and regulatory processes is needed to develop appropriate transformation and regeneration protocols for the crops of interest. Furthermore, the genes encoding the desired crop traits must be acquired, either through their own genomics research or through additional agreements with public- or private-sector organizations.
4. *The private sector provides access to know-how.* Because of the lead that private biotechnology companies have in terms of expertise and equipment, they could play an important role in training future developing-country experts. The problem associated with this, however, is that frequently the methods used to develop sophisticated biotechnology products cannot be employed in poorer countries due to the lack of suitable laboratory infrastructures. To make the training of future experts effective in the longer run, complementary capital investments in local research infrastructures must also be made. Aventis has created a fund that allows young PhDs from developing countries to absolve post-doc programs at various international universities. Of course, strengthening the local human capacities in developing countries of current or future commercial interest can facilitate the transfer, adaptation and application of proprietary technology.

4 CONCLUSION

Proprietary biotechnologies developed by the private sector are in many cases not readily adapted to the requirements of developing countries. Because of their necessarily high research investments, private companies focus on a limited number of key global crops that are often not the crops grown by resource-poor agricultural producers. So, while private companies can and do develop transgenic end-technologies for use by commercial farmers in a number of middle-income countries, the private-sector role in providing technologies to subsistence farmers in the least-developed countries is limited.

Nevertheless, in addition to contributing to human capacity building in developing countries, private companies could play a more important role in transferring intermediary technology components, such as proprietary genes or enabling techniques. The adaptation of proprietary technologies to local needs, however, requires in all cases: (i) proper regulatory mechanisms to secure international safety standards, (ii) enforceable intellectual property protection, (iii) national technology transfer infrastructures, including analytical capabilities to monitor genetically modified organisms, (iv) development investments, and (v) a functioning local seed industry. These capacities should be strengthened for the benefit of developing countries, if necessary with assistance by the international donor community. The role of international research organizations, for instance, could be to create elite events, partly on the basis of proprietary components, which would then be transferred to developing countries for further national adaptation (i.e., introgression into local varieties). Biotechnology is a technology that is amenable to do so many good things in terms of sustainable agricultural development that we have to identify ways in which the poorest countries can better participate. Collaboration between the private sector and the national and international public research institutes is the only way forward and should be encouraged within an agreed upon regulatory environment on specific projects and specific crops.

REFERENCES

James, C. (1999): Global Review of Commercialized Transgenic Crops: 1999. ISAAA Briefs, No. 12, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

USDA/APHIS (2000): Biotechnology Permits. United States Department of Agriculture, Animal and Plant Health Inspection Service, data retrieved from the internet: www.aphis.usda.gov/biotech/.

Chapter 20

BRINGING THE BENEFITS OF BIOTECHNOLOGY TO THE POOR: THE ROLE OF THE CGIAR CENTERS

Michael L. Morris and David Hoisington

Abstract: This paper examines the current and potential future role of the Consultative Group on International Agricultural Research (CGIAR) in bringing the benefits of biotechnology to the poor. The 16 CGIAR Centers currently invest around US $25 million annually on biotechnology, focusing mainly on conducting biotechnology research and building related research capacity in developing countries. In the future, they will have to direct more attention to strengthening national regulatory frameworks and promoting public awareness of biotechnology. In addition, the Centers can continue to play an important role in facilitating technology transfers by fostering innovative public-private and/or North-South partnerships. In the long run, the CGIAR Centers' success will depend on their ability to adapt to the changing environment in which agricultural research is carried out. A major challenge will be dealing with the growth of intellectual property rights, which are rapidly privatizing science and irrevocably altering the role of public research organizations.

1 INTRODUCTION

As the twenty-first century starts, a scientific revolution is transforming the field of agricultural research. Fueled by a series of technical breakthroughs that have greatly increased our understanding of molecular genetics, biotechnology has opened up exciting new opportunities for producing plant varieties and animal species with improved characteristics and even completely novel traits. Yet just when the fruits of the biotechnology revolution are starting to materialize, questions have arisen about who will reap the benefits. In a world in which those who conduct research face increasing pressure to generate financial returns, new

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technologies are increasingly being provided only to those who are able to pay for them; those who cannot afford the asking price often find themselves denied access. As a result, millions of poor people risk being excluded from the biotechnology revolution, especially in developing countries.

This paper examines the current and potential future role of the Consultative Group on International Agricultural Research (CGIAR) in bringing the benefits of biotechnology to the poor. Founded some 30 years ago to serve farmers in developing countries, the CGIAR has been extremely successful at filling gaps in the international research portfolio. Recent changes in the environment in which agricultural research is conducted, however, suggest that if the CGIAR is to continue to be successful in the future, it will have to change the way it operates. Whether or not the CGIAR will be able to reinvent itself quickly enough to maintain its status as a major player in the international research arena remains very much an open question. One of the key factors likely to determine its success in completing the transformation will be its ability to embrace biotechnology.

The paper is divided into nine parts, including this introduction. Section 2 briefly introduces the CGIAR and describes the biotechnology-related activities currently being conducted by the 16 international agricultural research centers that are supported by the CGIAR (referred to here as "the CGIAR Centers" or simply "the Centers"). Sections 3 and 4 discuss the role of the Centers with respect to two areas in which they are already active: conducting biotechnology research and building biotechnology capacity in developing countries. Sections 5 and 6 discuss the role of the Centers with respect to two areas in which they will have to become much more active: strengthening regulatory frameworks and promoting public awareness of biotechnology. Section 7 focuses on the role of the Centers in facilitating transfers of biotechnology from industrialized to developing countries. Section 8 discusses the growing importance of intellectual property rights (IPRs) and describes how the privatization of science is placing new pressures on public research organizations. Section 9 summarizes the main points and concludes with a brief discussion of the road ahead.

2 THE CGIAR AND BIOTECHNOLOGY: AN OVERVIEW

2.1 Overview of the CGIAR

Established in 1971, the CGIAR is an informal association of 58 public and private sector members that supports a global network of 16 international agricultural research centers (Table A 1 in Appendix A). The

CGIAR's budget for 1998 totaled approximately US $345 million. The World Bank, the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Program (UNDP), and the United Nations Environment Program (UNEP) are co-sponsors of the CGIAR, although funding comes mainly from industrialized countries in the form of official development assistance grants. The CGIAR's mission is to contribute to food security and poverty eradication in developing countries.

Research within the CGIAR is carried out by the individual Centers, whose research mandates include crop and livestock improvement and natural resource management. In addition to their direct involvement in research, the Centers engage in activities designed to protect the environment, preserve biodiversity and strengthen local research and policy-making capacity. The Centers' total investment is currently allocated among these activities as follows: increasing productivity (40%), protecting the environment (17%), saving biodiversity (11%), strengthening national agricultural research systems (21%) and improving policies (11%).

During the first two decades of their existence, at a time when global food production growth still lagged behind population growth, and policy-makers were worried about averting widespread famine, many of the CGIAR Centers responded to the most urgent need of the day by focusing on productivity-enhancing research targeted at major food crops. Great progress was achieved in improving crops of global importance, including cereals, grain legumes, roots and tubers, and bananas and plantains. More recently, greater concern for the broader physical and institutional context in which development takes place has led to a wider focus, with the result that all of the Centers now devote increased attention to environmental and resource management issues, as well as human capital development and institution building.

Despite the recent shift in focus, the CGIAR Centers remain at the forefront of germplasm improvement activities in the developing world. In addition to providing training for developing-country scientists, many Centers serve as hubs of global breeding networks. Through these networks, which operate with the active participation of partners from national agricultural research systems (NARSs), plant and animal germplasm is collected, evaluated, improved and re-distributed in a continuing, iterative process. Improved germplasm developed with the help of CGIAR scientists has made its way into crop varieties that today are planted on millions of hectares, leading to enormous gains in production and generating billions of dollars of benefits for producers and consumers (Evenson, 1999; Anderson and Dalrymple, 1999).

A distinctive feature of the CGIAR is that many of the Centers' products and services are distributed free of charge. This free distribution policy is consistent with the idea that the Centers are publicly funded, not-for-profit research organizations that operate for the good of society and therefore need not concern themselves with commercial, income-generating activities undertaken for cost recovery. In the past, the free distribution policy was extremely effective for ensuring the rapid and widespread dissemination of CGIAR products and services, particularly improved crop varieties. Now, however, changes in the way research is organized and funded threaten to undermine the sustainability of the CGIAR model and raise daunting new challenges that the Centers will have to overcome if they are to build on their past records of success.

2.2 CGIAR Policy on Biotechnology

Biotechnology, the focus of this paper, represents an important new tool for crop and animal improvement research and therefore has attracted considerable attention on the part of the CGIAR. During the past decade, the topic of biotechnology has become increasingly prominent in the various fora in which CGIAR policies are debated and decided. Unfortunately, the many discussions about biotechnology in the CGIAR have resulted in few concrete outcomes. To date, the CGIAR has been unable to develop a formal policy on biotechnology, which perhaps is not surprising considering the often divergent views held by its large and varied membership (CGIAR, 1998a).

Reluctant to wait for the CGIAR members to reach a consensus about biotechnology, the Centers have taken steps to improve their ability to respond to developments in this rapidly evolving field. In 1998, the Centers issued a position statement summarizing their position on biotechnology (see Appendix B). Key points to note about the position statement are that it (i) strongly endorses the potential value of biotechnology as a tool for meeting the objectives of the CGIAR, (ii) signals the Centers' intention to invest in biotechnology-related research as appropriate, and (iii) confirms the Centers' commitment to strengthening the capacity of public and private organizations in developing countries to develop, deploy and manage biotechnology processes and products.

2.3 Biotechnology Research in the CGIAR

Individual CGIAR Centers have embraced biotechnology to varying degrees, depending on the usefulness of biotechnology tools and products to each Center's research programs. Table A 2 in the Appendix presents data on biotechnology investments being made by the Centers and lists the principal biotechnology research activities. Because several Centers do not maintain separate budgets for biotechnology research, the investment figures should be considered approximate; in the case of these Centers, biotechnology research expenditures were estimated indirectly.

Currently, 11 CGIAR Centers engage in biotechnology research. Of these 11 Centers, nine invest over US $1 million per year in biotechnology. The Center with the largest investment is ILRI, whose $6.5 million biotechnology budget supports work on characterization, conservation and use of animal genetic resources; development of disease-resistant livestock; and immunology and vaccine development.[1] Significant investments are also being made by Centers that maintain major plant breeding programs, notably IRRI (rice), CIMMYT (maize, wheat), ICRISAT (sorghum, millet, pigeon peas, chickpeas, groundnuts), IITA (cassava, maize, cowpeas, soybean), ICARDA (barley, wheat, lentils, chickpeas), and WARDA (rice). Another Center with a significant investment in biotechnology is IPGRI, mainly through its banana and plantain improvement programs.

Collectively, the CGIAR Centers currently invest around US $25 million annually on biotechnology, representing approximately 7.7 percent of the total CGIAR budget. These figures are substantial, but it is important to recognize that in terms of the overall level of investment, the CGIAR remains a minor player in the global biotechnology industry. Few data are available on total private sector expenditures for crop biotechnology research, but considering that private-sector investment in food and agricultural research is denominated in billions of US dollars, the size of the CGIAR investment must be kept in perspective (Fuglie et al., 1996).

3 THE ROLE OF THE CGIAR IN BIOTECHNOLOGY RESEARCH

3.1 Focus of CGIAR Biotechnology Research

Most biotechnology research carried out by CGIAR Centers is related in one way or another to germplasm improvement (ILRI's work on animal vaccines is a significant exception). Biotechnology is viewed as an important new tool for building on the Centers' traditional strengths in breeding improved plants and animals. In addition to accelerating and enhancing germplasm improvement efforts, biotechnology applications are expected to add tremendous value to the Center-held plant germplasm collections. Characterization of genetic diversity at the molecular level and accumulation

[1] See Appendix Table A 1 for the full names of the individual Centers.

of knowledge about functional genomics will facilitate the exploitation of the vast store of untapped genetic potential that exists in the Center-managed genebanks. In terms of benefits to the poor, productivity gains associated with increased use of these germplasm collections could well turn out to be the most important benefit to flow from the Centers' investment in biotechnology.

No attempt will be made here to review systematically all the biotechnology research currently being done by the CGIAR Centers. Detailed information about this topic is available through the Centers' respective publications, especially their annual reports, as well as through their web sites. Generally speaking, however, biotechnology-related research within the CGIAR falls into eight categories, each of which is described briefly below: genetic diversity studies, gene mapping, gene discovery, tissue culture, genetic engineering, pathogen detection, vaccine development and policy analysis.

Genetic diversity studies. Molecular characterization of genetic resources can provide valuable information for classifying parent materials, tracking genes across cycles of selection, and identifying optimal alleles for specific traits. All of the Centers that conserve genetic resources or conduct breeding research use biotechnology-based techniques, especially molecular markers, to characterize genetic materials (not only materials maintained in genebanks or used in breeding programs, but also pests and pathogens). The high cost of molecular characterization techniques once required most Centers to limit their efforts to selected materials, but dramatically cheaper, high-throughput methods should make it possible to initiate large-scale characterization for more extensive collections of genetic resources.

Gene mapping. Gene mapping involves identifying and locating the gene or genes associated with a particular trait. As information about individual genes is accumulated, it can be combined to produce maps of entire genomes. Many Centers are using molecular markers to develop genetic maps. Genetic maps are of interest in and of themselves, because they allow for better understanding of the organization of a particular species and facilitate comparisons between related species. Genetic maps are additionally useful for applied breeding programs, because they provide the information needed to transfer specific alleles through marker-assisted selection techniques. Several Centers have successfully linked molecular markers to major qualitative genes, such as the genes that confer resistance to African mosaic virus in cassava (CIAT), to maize streak virus (CIMMYT), and to rice bacterial leaf blight (IRRI). Efforts are underway to clone these genes and to move them into new varieties via marker-assisted selection. Many agronomic traits that are important to breeding programs are quantitative in nature and thus difficult to dissect genetically. Such traits include resistance to abiotic stresses (drought, low soil fertility), resistance to biotic stresses (diseases, insects) and ultimately yield. All of the Centers that work on crop improvement are using molecular markers to map the quantitative trait loci (QTL) associated with these traits, and a few have already completed pilot projects designed to evaluate the value of using marker-assisted selection for improving quantitative traits in breeding programs.

Gene discovery. Gene discovery involves isolating and characterizing novel gene sequences and determining their functions. Since this is essentially basic research, it is difficult to know in advance if the results will have practical applications, so until now gene discovery has attracted relatively little attention from the Centers. With recent advances in technology that have dramatically reduced research costs, however, the Centers' efforts in this area are likely to increase. The natural extension of gene discovery work will be to clone the genes that control economically important traits. Although gene cloning is neither routine nor easy (except in a few model species, such as *Arabidopsis*, rice and maize), new methods based on genome similarities, candidate genes, DNA sequence databases, micro-arrays and proteomics provide powerful new approaches and are being explored by the Centers. One problem with many of the new gene cloning methods is that private companies often own the enabling technology. If the Centers are to develop strong in-house capacity to carry out gene cloning, they must quickly learn how to negotiate agreements and/or partnerships that will allow them to access key technology and information.

Tissue culture. Tissue culture involves regenerating entire functioning organisms from single cells. Tissue culture is finding a number of applications within the CGIAR. Many Centers are using tissue culture techniques to preserve and regenerate genetic resources, as well as to produce virus-free planting materials for farmers. Micropropagation through tissue culture is particularly useful with diploid species, including potatoes, cassava, cowpeas, chickpeas, and bananas and plantains. Micropropagation of cereal species has not proven practical or cost-effective, although embryo rescue procedures based on tissue culture techniques are important in barley and wheat breeding for producing doubled haploids.

Genetic engineering. Tissue culture techniques play an integral part in genetic engineering, which involves the transfer from one organism to another of genes that code for desirable traits. Virtually all CGIAR Centers that engage in crop improvement activities are working with genetically engineered crop varieties. This work initially targeted relatively simple traits, such as resistance to insects, viruses and fungal pathogens, although it is hoped that eventually genetic engineering techniques will be used to address more complex traits, such as tolerance to drought and low soil fertility, and ultimately even yield. Several Centers are working to enhance the nutritional quality of food crops by engineering higher levels of critical vitamins and micronutrients. Recent reports of success in raising the vitamin A and iron content of rice suggest that genetic engineering could play an important role in the production of nutritionally improved crops tailored specifically to the needs of developing countries. Working closely with the authorities in their respective host countries, a few Centers have started evaluating transgenics in the field, while many others are seeking authorization from local regulatory agencies to implement field trials.

Pathogen detection. Biotechnology provides a number of avenues for pathogen detection. ELISA-based techniques and more recently developed DNA-based detection systems provide extremely sensitive means of identifying specific pathogens and precisely quantifying the amounts that are present. Several Centers routinely use these techniques to detect important plant viruses. Biotechnology-based pathogen detection systems can also be used with animal diseases, and ILRI is currently developing detection systems for several important livestock diseases. This work is expected not only to generate cost-effective detection systems but also to help identify opportunities for better prevention methods.

Vaccine development. Since it applies only to animals, vaccine development takes place only at ILRI. One of the issues in vaccine development is how to commercialize the production and distribution of the product. ILRI's vaccine work has targeted diseases that affect mainly small-scale livestock producers. Because these producers frequently lack the means to purchase commercial veterinary products, it is often difficult to attract significant interest in the commercial production of these vaccines.

Policy research. The "hard" biotechnology research conducted at CGIAR Centers is complemented by policy research that focuses directly or indirectly on biotechnology. Most of this research relates to one of three broad areas of investigation: (i) evaluating the economic costs and benefits of biotechnology research, (ii) assessing the potential impacts of biotechnology (e.g., economic, political, social, environmental), and (iii) managing intellectual property associated with biotechnology. The results of this policy research are expected to have several applications. Research managers, both within the Centers and within national research systems, can potentially use information about the economic costs and returns of biotechnology research to more efficiently allocate research resources. Information about the likely impacts of biotechnology and the effects of alternative regimes for managing intellectual property can potentially be used by government decision-makers to formulate policies that will ensure the widespread and equitable sharing of biotechnology's benefits.

3.2 Biotechnology Research Strategy

What has been the CGIAR's overriding strategy with respect to biotechnology research? Generally speaking, most Centers have sought to make the use of biotechnology need-driven rather than technology-driven. In other words, instead of investing in biotechnology for its own sake, the Centers have attempted to identify areas in which biotechnology offers an advantage in terms of time and/or cost over conventional research methods. Consistent with this philosophy, many Centers have positioned themselves toward the downstream (applied) end of the research spectrum, for the most part avoiding upstream (basic) research and concentrating instead on developing applications for technologies developed by others. This strategy makes sense, given the limited resources at the Centers' disposal relative to other players (e.g., the multinational life-science companies) and the high cost of cutting-edge biotechnology research. It has allowed the Centers to exploit technology that is already available and to immediately put it to use in developing products that can be delivered to national program partners in the shortest possible time.

All in all, this strategy has been extremely successful. As Centers have developed in-house expertise in biotechnology, they have been able to identify technology with potential utility for their ongoing germplasm improvement work. Once a particular technology is identified and mastered, attention shifts to devising methods for using the technology on a routine basis in an applied germplasm improvement program. Many Centers are still in this scaling-up phase, which involves acquiring or developing equipment capable of handling large volumes of samples. Other Centers have made significant progress in this respect, to the point that high-throughput systems are up and running. In these Centers, biotechnology techniques will soon become a routine, integral component of the germplasm improvement research.

But not all of the Centers have integrated biotechnology into their research programs at the same rate. Reasons for the uneven rate of progress vary. Some Centers have lagged in developing in-house capacity to conduct biotechnology research because biotechnology methods have not appeared to offer advantages relative to traditional research methods. Other Centers' plans to expand into biotechnology have been slowed by funding shortages, or delayed because management underestimated the time needed to negotiate the initial, steep portion of the learning curve. All of the Centers, however, face the formidable challenge of establishing biotechnology research capacity during a period when the knowledge frontier continues to expand exponentially, often making state-of-the-art techniques and equipment obsolete within months of their introduction. Biotechnology researchers are having to learn how to operate in an environment that differs significantly from conventional plant breeding, in which basic selection methods and strategies have changed relatively little over the years.

Although the CGIAR Centers have tended to emphasize applied rather than basic research, not all of their biotechnology work has involved the application of technology developed by others. Most of the Centers work on staple food crops grown mainly in the developing world, such as sorghum, pearl millet, cassava, beans, lentils, chickpeas, cassava, sweetpotatoes, bananas and plantains. Many of these crops have attracted little attention from biotechnology researchers in industrialized countries, so the Centers have often had to innovate. In a number of cases, the Centers are carrying out research at the very frontiers of science.

One distinctive feature of the CGIAR's biotechnology research is its focus on the need to adapt technologies to the circumstances of developing countries. For various reasons, research materials and methods that can be used in the North are sometimes inappropriate in the South. In such cases, the Centers have devised ways to circumvent the constraint. For example, some early visualization techniques for molecular marker work relied on radioactive tags, but since radioactive materials cannot be handled safely in many developing countries' laboratories, CGIAR researchers developed visualization techniques based on photoluminescent tags. Similarly, some of the early gel electrophoresis procedures involved the use of expensive chemicals and membranes, so CGIAR researchers developed alternative procedures based on more affordable materials. Finally, many laboratory procedures require the use of proprietary substances (such as enzymes and promoters) that are not readily available in developing countries, and CGIAR researchers have developed alternative procedures that use only available materials.

4 THE ROLE OF THE CGIAR IN BIOTECHNOLOGY CAPACITY-BUILDING

In addition to conducting biotechnology research, many CGIAR Centers have invested considerable effort in building biotechnology research capacity within national programs. This activity is consistent with the CGIAR's mandate to strengthen NARSs. Two main areas of emphasis can be distinguished: (i) training people, and (ii) building institutions.

4.1 Training People

Now that their own biotechnology research facilities are up and running, many CGIAR Centers are stepping up their efforts to train national program scientists in biotechnology research procedures. Although few have actually done so, many agricultural research organizations in developing countries are interested in establishing biotechnology programs, and the demand for training is considerable. At the same time, the interests, needs and levels of technical expertise vary considerably among individual countries, making it difficult for the Centers to design large-scale, formal courses. Accordingly, biotechnology training is often handled on a case-by-case basis, with instruction tailored to meet the specific needs of individual countries or even individual institutions.

One approach that has proven particularly effective is for Centers to host developing-country biotechnology researchers for extended visits. The duration of these visits varies, ranging from 3-6 months to several years. During their stay with the Center, the visiting researchers typically rotate through a number of departments and spend time working with the Center scientists in their laboratories. Such hands-on training provides the visitors with valuable opportunities to familiarize themselves with the theoretical aspects of biotechnology research and to learn about the logistical aspects of running a working laboratory.

In addition to providing hands-on training, many of the Centers offer formal courses in biotechnology research methods. Generally, these courses are offered at the Centers to take advantage of the Centers' laboratory facilities, although they are sometimes offered elsewhere. The typical course involves 2-3 weeks of instruction, often combined with laboratory work. Center-sponsored courses have covered topics such as DNA molecular marker techniques, the use of molecular markers to characterize diversity, the integration of marker-assisted selection into plant breeding programs, tissue culture, and genetic engineering and transformation technologies.

A third strategy that the Centers use to strengthen human capital in developing countries is to organize and coordinate collaborative research networks. Examples include the Asian Rice Biotechnology Network (coordinated by IRRI), the Asian Maize Biotechnology Network (coordinated by CIMMYT) and the Latin American Biotechnology Network (coordinated by CIAT), which link researchers from national programs, international organizations and advanced research institutes (ARIs) in the North. By fostering regular communication (mainly through email and newsletters) and by sponsoring periodic meetings, these networks have facilitated flows of biotechnology-related information, products and technology.

4.2 Building Institutions

For developing countries that are trying to establish biotechnology research capacity, there is little point in training scientists if these scientists lack research facilities. A second important aspect of capacity building, therefore, is to build institutions where biotechnology research can be carried out. The CGIAR Centers support the efforts of many developing countries to establish biotechnology research organizations, but realistically the role of the Centers is restricted to that of providing technical advice. Given the limited resources at their disposal, the Centers are not in a position to provide the funding needed to establish and operate a well-equipped, state-of-the-art biotechnology research facility, which would cost millions of US dollars (Maredia, 1999; Falconi, 1999). Funding of this order of magnitude can come only from the local government or from some external source (e.g., a multilateral lending organization or bilateral assistance donor).

Even if the CGIAR Centers have not financed the construction of biotechnology research facilities, they have provided advice on equipping, staffing and managing such facilities. In some cases, the advice has been provided informally; in other cases, the advisory role has been institutionalized. ISNAR has been particularly active in this area through its ISNAR Biotechnology Service (IBS), which serves as an independent advisor to developing countries on policy and management issues related to agricultural biotechnology. Established in 1993, IBS provides services based on the systematic analysis of policy and management needs and issues. It seeks to be neutral and non-prescriptive, advancing recommendations and stimulating informed decision-making based on knowledge gained through research, seminars and needs analysis.

5 THE ROLE OF THE CGIAR IN STRENGTHENING BIOTECHNOLOGY REGULATIONS

Of the many products developed using biotechnology, relatively few have been approved for commercial release in developing countries. This is particularly true of transgenic plants and animals, which are used in many industrialized countries but have made few inroads in the developing world. In developing countries a major impediment to the deployment of products developed using biotechnology, especially transgenic crops, is the lack of effective regulatory systems (Lewis and Johanson, 1999). Most industrialized countries regulate the development, testing, commercial planting and consumption of genetically engineered crops to ensure their safety for humans, animals and the environment. Most developing countries, however, lack procedures to regulate these activities, and efforts to deploy biotechnology products, especially genetically engineered crops, are frequently held up.

One reason why more developing countries have not introduced regulations to monitor biotechnology research is that they lack the necessary expertise. This is not surprising, considering their limited experience with biotechnology and the scarcity of information about the long-term performance of many biotechnology products. Efforts to establish biotechnology regulations are further complicated because the knowledge needed to assess the safety of biotechnology products generally resides with those who have an obvious interest in promoting their use (e.g., private corporations seeking approval for commercial products). Policy-makers in many developing countries are understandably reluctant to rely on private corporations for advice about establishing biotechnology regulations.

In this context, the CGIAR has a potential role to play as an honest broker. Since the Centers do not have a commercial interest in promoting the products of biotechnology research, they are viewed by many developing country policy-makers as a reliable source of unbiased technical advice about the establishment of effective regulatory systems. Requests addressed to CGIAR Centers to provide assistance in this area have increased in recent years and are likely to proliferate as more countries develop biotechnology programs. Most of these requests relate to two areas: (i) regulation of research procedures and (ii) field-testing and release of genetically engineered crops.

In response to increasing requests, the Centers have begun to step up their efforts to help developing countries introduce effective regulatory systems. These efforts have in some instances included formal training. For example, several Centers have hosted workshops on developing and implementing biosafety regulations, and some have offered courses that provide practical training for future biosafety officers. Not all of the Centers' efforts in this area have involved formal training; some support has been much more hands-on. A number of the Centers involved in biotechnology research have been working closely with local officials in partner countries to design and implement laboratory biosafety regulations and field-testing procedures for transgenics (Alvarez-Morales, 1999). Center staff also serve on organizations that are involved in setting biotechnology policy.

6 THE ROLE OF THE CGIAR IN PROMOTING PUBLIC AWARENESS

Another way that the CGIAR can make an important contribution is by promoting greater public awareness about biotechnology research and its products. Nobody needs to be reminded about the heated controversy that has erupted in many countries over biotechnology, particularly genetic engineering and its products. It seems as if every day brings new reports of the latest salvos in the long-running war being waged in the media over the profitability, safety and social desirability of transgenic plants and animals. Some of the more non-discriminating critics have gone so far as to condemn all products and research procedures that are remotely connected to biotechnology. They have called for a complete ban not only on transgenics, but also on biotechnology research per se.

Until now, the CGIAR has refrained from staking out a clear position on genetic engineering. This is hardly surprising; the membership of the CGIAR encompasses a wide range of views, and it would probably be impossible to reach consensus on such a contentious topic. The Centers have been more proactive about biotechnology, as evidenced by their release of the Centers' Position Statement on Biotechnology, but they, too, have maintained a low profile when it comes to transgenics.

The CGIAR's conspicuous silence has a cost, however, because public discussion about biotechnology in general and genetic engineering in particular frequently ends up being driven by incomplete information, half-truths or downright falsehoods. To some extent, this is to be expected; the science involved is after all quite complicated, and it is probably unrealistic to expect that the finer points of technical arguments will be understood completely by non-scientists. Still, the fact that an issue involves complicated scientific information does not mean that policy decision-making should be reduced to choosing among a simplified set of choices that gloss over important technical details. And it certainly does not mean that scientifically unsupportable statements should be foisted off on the public as fact, which is what seems to occur too often.

To some extent, the Centers' reticence to participate in the public discussion over the potential role of genetically engineered plants and animals in helping to feed the developing world's poor reflects a suitably cautious approach to a complicated issue. Clearly one reason why the Centers have been unwilling to voice their opinions is that sufficient data have not always been available to determine whether the likely benefits of transgenics outweigh the potential costs. But the Centers' timid posture may also reflect their fear of alienating either of the debate's two main parties – at one extreme the non-governmental organizations (NGOs) that vociferously oppose transgenics, and at the other extreme the private corporations that vigorously promote them.

It is understandable that the Centers should want to avoid taking sides in the public debate about genetic engineering, but one unfortunate consequence of their reluctance to participate is that an important point of view is not always expressed, with the result that the debate is often unbalanced. While there is no shortage of organizations that claim to speak for the developing world's poor, many of the most outspoken participants in the debate about genetic engineering come from industrialized countries. Thus one must question the extent to which their arguments are shared by the developing world's poor.

When it comes to biotechnology in general and genetic engineering in particular, the interests of people who live in developing countries may not always be identical to those who live in industrialized countries. Prince Charles and Greenpeace may be correct when they say that transgenic plants and animals are unnecessary in Europe, where the cost of raw commodities makes up a small fraction of the final price paid by consumers for heavily processed, elaborately packaged, and extensively advertised food, but it is hard to make the same argument in developing countries where millions go to bed hungry every night because food is unavailable or unaffordable. In places where there is often not enough food to go around and where food prices directly affect the incomes of a large proportion of the population, the potential productivity gains offered by transgenics cannot easily be ignored (Pinstrup-Andersen, 1999). Policy-makers in many developing countries argue, therefore, that European and North American groups opposed to genetic engineering have no right to try to suppress the technology at the global level.

The argument that European and North American consumers should at least have the right to decide whether or not genetically modified food should be permitted in their own countries is also more controversial than would first appear, since in today's highly globalized economy, it makes little difference where the productivity gains made possible by biotechnology are achieved. If we accept that wealthy industrialized countries have a moral responsibility to provide assistance to less fortunate developing countries, then it follows that industrialized countries would be shirking their moral responsibility by banning biotechnology, if banning biotechnology means foregoing opportunities to generate food and technology that could be used to help developing countries. Following this logic, it is not only morally unacceptable for those who live in industrialized countries to call for a global ban on biotechnology, but it is also morally unacceptable for them to try to suppress biotechnology in their own countries, since in the end this will harm poor people in developing countries.

Another area in which the interests of developing countries may diverge from those of industrialized countries is not related to the matter of ensuring an adequate food supply. Rather, it relates to the potential of biotechnology to serve as a source of economic growth. In many industrialized countries, investments in biotechnology research have generated a large number of productivity-enhancing processes and products whose impacts have been felt far beyond agriculture, for example in the pharmaceutical and manufacturing sectors. Policy-makers from several developing countries have alleged that if biotechnology research is suppressed now, before developing countries manage to develop their own expertise, then the industrialized countries will be able to effectively "lock in" their huge technological lead, with the result that developing countries will be denied access to an important source of potential productivity gains and employment.

Whether or not these arguments in favor of putting biotechnology to work for the benefit of the developing countries are correct is in a sense immaterial – the point is that they are arguments that need to be articulated clearly and subjected to informed public debate. By providing credible information about views that may not always coincide with the views of those with the loudest voice or the largest public relations budget, the CGIAR Centers could play an important role in promoting greater public awareness about biotechnology, both in developing as well as in industrialized countries. Obviously the Centers must not blindly promote biotechnology as the panacea for all of the developing world's problems; a number of concerns still need to be addressed concerning the need for and safety of some biotechnology products, including certain types of transgenics. But given the relative paucity of accurate, scientifically correct and objective information, the Centers could help to inject scientific rigor and intellectual honesty into the debate.

After a long period of relative inactivity in this area, the CGIAR seems to be increasingly willing to provide a public forum for scientific discussion and review. In October 1999, the CGIAR joined forces with the US National Academy of Sciences (NAS) to sponsor the International Conference on Biotechnology, held in Washington, DC. The conference had two key objectives: (i) to broaden awareness of developing countries' views on issues associated with biotechnology, their experiences with its use and their needs and priorities, and (ii) to contribute to a science-based understanding of the issues and public concerns related to biotechnology and how these might be addressed.

7 THE ROLE OF THE CGIAR AS A FACILITATOR

One important – and often underappreciated – role of the CGIAR is that of a facilitator. Over the years, many CGIAR Centers have established close working relationships with organizations that likewise are involved in agricultural research, including public-sector national agricultural research organizations in developing countries (NAROs), advanced research institutes in industrialized countries, national and multinational private firms and not-for-profit NGOs. Even when the goals of these organizations overlap, as they often do, effective collaboration may be prevented by differences in funding structures, operating philosophies and cost recovery policies.

Consistent with its mission to strengthen research capacity, the CGIAR has formed partnerships with organizations from across the institutional spectrum. In the past, many of the partnerships tended to be bilateral, and most focused on narrowly defined technical problems. More recently, as it has become apparent that finding solutions to many of the most intransigent development problems requires not only technical innovation but also institutional reform and political commitment, the number of partnerships has proliferated, as has their complexity. One clear sign of this has been the growing number of collaborative research networks that bring together different types of organizations. For example, most of the commodity Centers participate in networks whose membership includes ARIs (whose function is to perform basic germplasm improvement research), NAROs (whose function is to adapt improved varieties to local circumstances), private firms (whose function is to produce improved seed) and NGOs (whose function is to deliver the improved seed to farmers, along with extension advice).

CGIAR Centers are often the motivating force behind these networks and frequently serve as the glue that binds them together. The Centers are able to perform this function because their reputation for scientific excellence and political non-partisanship makes them acceptable to other network members as neutral brokers. Participation by a CGIAR Center in a network often gives the network a certain legitimacy in the eyes of the other members and increases their confidence that the terms of the networking agreement will be upheld and respected. Through their involvement in these consortia, the Centers have been instrumental in organizing collaborative research-technology transfer arrangements that will allow biotechnology processes and products to flow from research organizations in the North to research organizations in the South.

8 THE INCREASING IMPORTANCE OF INTELLECTUAL PROPERTY

The CGIAR Centers' biotechnology research has forced them to confront a number of difficult issues regarding the ownership and management of intellectual property. This includes not only intellectual property owned by third parties that the Centers must access in order to carry out their work, but also intellectual property produced by the Centers themselves (Barton and Siebeck, 1992; Cohen, 1999). Intellectual property issues are not unique to biotechnology, but because they play a greater role in biotechnology than in most other fields in which the Centers have traditionally been active, the move into biotechnology has brought these issues into the forefront.

In developing in-house capacity to carry out biotechnology research, many Centers have used proprietary equipment, materials, laboratory techniques, and/or information owned by others (Cohen et al., 1998; Cohen, 1999). Use of third-party intellectual property has in many cases been unavoidable, since alternative ways of accomplishing particular tasks frequently are not available. Several different mechanisms have been used by Centers to obtain access to third-party intellectual property, including commercial licenses, formal agreements under which the Centers have been granted limited rights to use a technology for research purposes only, and informal arrangements under which the terms of use have not been clearly specified. In some cases, Centers have acquired proprietary technology without formal authorization of any kind.

Since the CGIAR Centers are publicly funded institutes that traditionally have not been concerned with commercializing their products, it is perhaps understandable that intellectual property issues initially were given relatively little attention. Nevertheless, when the first products developed with the use of third-party technology began to appear, many Centers came to regret their less-than-exacting approach to the acquisition and use of third-party technology. In a number of instances, individual Centers found that third-party owners of intellectual property were unwilling to permit distribution of products developed with the use of their proprietary technology. This meant that many Centers did not have what the private sector terms "freedom to operate". In such cases, Centers have had little choice but to negotiate use-rights with the owners of the technology. Frequently, the Centers find themselves in a difficult position, since they usually lack resources to pay for the technology up front and yet have no intention of commercializing their research products (which would at least allow them to negotiate on the basis of expected future revenues).

Having learned an important lesson, the CGIAR Centers have sought to ensure that these mistakes will not be repeated. All Centers are currently conducting or will soon initiate comprehensive intellectual property audits to identify intellectual property produced by the Center, as well as third-party intellectual property being used by the Center. Once these audits are completed, each Center will be in a position to devise an effective strategy for securing legal rights to use third-party intellectual property needed by its research programs. In addition, each Center will be able to evaluate more objectively the potential commercial value of intellectual property produced by its own scientists.

Although the intellectual property audits were originally motivated by the need to ensure that each Center had freedom to operate, they represent the beginning of what is likely to be a profound change in the way the CGIAR operates. The question of how to handle intellectual property is easily the most critical issue facing the CGIAR today. Individually and collectively, the Centers are grappling with the question of whether they should seek legal rights to the intellectual property created by their research programs.

Opinions regarding this highly controversial issue vary widely. Some oppose the idea of CGIAR Centers seeking legal rights to their intellectual property. These are mainly smaller developing countries and some NGOs, who argue that since the Centers are publicly funded institutes, the products of their research programs should remain freely available to all. Furthermore, argue these opponents, many of the products coming out of CGIAR research programs are developed in collaboration with partner organizations, especially national agricultural research programs, so the Centers cannot justify claiming legal rights exclusively for themselves.

Others support the idea of CGIAR Centers seeking legal rights to their intellectual property. These are mainly larger developing countries and private firms, who argue that if the Centers do not protect the products of their research programs, the rights will be appropriated by others and used for the benefit of the few. In today's increasingly commercialized and highly competitive environment, argue these proponents, if the Centers do not take steps to protect their intellectual property, unscrupulous opportunists will not hesitate to do so, potentially denying the Centers and their clients access to technologies which they themselves developed.

As noted earlier, the CGIAR Centers have not reached a consensus on this difficult question, whose importance cannot be overstated. The future role of the Centers in bringing the benefits of biotechnology to the poor will depend to a large extent on policies adopted with regard to intellectual property. As agricultural research becomes more and more privatized, access to critical technology is becoming increasingly restricted (Sederoff with Meagher, 1995). True, many proprietary technologies owned by private firms are available to those willing and able to pay commercial licensing fees, but these fees are often beyond the reach of the Centers.

Currently, many Centers are re-assessing their policies regarding intellectual property (CGIAR, 1998b). Two compelling arguments can be made in favor of the Centers seeking legal rights to the intellectual property they produce. The first revolves around the concept of "defensive protection" and is based on the premise that if the Centers do not take steps to protect the intellectual property they produce, others will, raising the possibility that the Centers themselves, as well as their partners and clients, could be denied access. The second argument revolves around the concept of creating "bargaining chips" and stipulates that Centers will be able to improve their access to intellectual property owned by others if they can secure legal rights to their own intellectual property, which could then be offered in exchange for usage rights from owners of third-party intellectual property.

These arguments in favor of the Centers seeking legal rights to the intellectual property that they produce are offset by several opposing arguments. To begin with, establishing and defending IPRs is time-consuming and expensive. Most commercial agri-biotechnology firms have legal departments staffed by specialized patent attorneys and technology licensing specialists whose sole purpose is to file patent applications and negotiate licensing agreements. All CGIAR Centers lack such expertise and would have to invest considerable amounts of money to acquire it – money that would have to be diverted from their research programs. In addition, some feel that if the Centers enter into this game, it will be difficult to avoid the temptation to focus research activities on areas of potential commercial interest, which runs counter to the mission of publicly funded research organizations dedicated to serving the needs of the poor.

Even as the CGIAR continues to debate alternative strategies for dealing with intellectual property, circumstances are forcing many Centers to move in the direction of stronger protection. Most of the impetus has come from the growing number of collaborative research agreements being signed with private-sector partners, many of whom are understandably concerned about retaining proprietary rights to any jointly produced intellectual property. In an effort to satisfy the objectives of all partners, collaborative research agreements increasingly include provisions designed to segment the market for any jointly-developed technology, for example by granting the private-sector partners exclusive rights to sell the technology in commercial markets, while allowing the Centers to distribute the technology free in non-commercial markets.

9 SUMMARY AND CONCLUSION

Although united by a common mission, the 16 international agricultural research centers supported by the CGIAR are very diverse. No two Centers are exactly alike; each features a unique mandate, organizational structure, set of clients, geographical focus and work program. Given the many differences between Centers, the title of this paper is somewhat unfortunate. The Centers have embraced biotechnology for different purposes, at dissimilar rates and to varying degrees, so it is misleading to imply that they have a common role to play in bringing the benefits of biotechnology to the poor.

Despite their dissimilarities, however, it is possible to identify areas in which the CGIAR Centers as a group can play an important role in bringing the benefits of biotechnology to the poor. In this concluding section, we discuss areas in which the Centers are already active, before turning to areas in which they are likely to become more active in the future.

9.1 Current Role of the Centers

With a combined investment in biotechnology that currently exceeds US $25 million per year, the CGIAR Centers are strongly committed to biotechnology. As a tool for creating economically valuable crop varieties and animal species, biotechnology is too valuable to ignore. The Centers recognize that they must develop expertise in biotechnology if they are to achieve their mission and remain global leaders in agricultural research.

Until now, the Centers have focused on developing in-house capacity to perform biotechnology research, as well as on building capacity among national program partners. Four salient points emerge from this brief review of biotechnology activities currently pursued by the CGIAR Centers:

1. Use of biotechnology by CGIAR Centers tends to be need-driven, rather than technology-driven. Individual Centers are, where appropriate, investing in biotechnology research, but only when such investment is likely to help achieve the Centers' missions. Given the modest budgets of most Centers relative to total private-sector investment in biotechnology research, it generally is most efficient for the Centers to concentrate on applications, rather than on basic research, but in cases where basic research is warranted, this is also being undertaken.
2. Most CGIAR Centers are seeking to complement, rather than compete with, biotechnology research being done elsewhere. Biotechnology research in the private sector is targeted mainly at crop species and animal breeds grown by commercial farmers in the North; relatively

little private-sector biotechnology research is targeted at crop species and animal breeds grown by subsistence-oriented farmers in the South. Given their traditional strong links to research organizations in the developing world, as well as their mandate to serve the poor, the Centers have a comparative advantage focusing on the technology needs of the South.

3. In addition to conducting biotechnology research, most CGIAR Centers are investing considerable resources into capacity-building activities designed to assist developing countries in managing biotechnology for themselves. Capacity-building activities supported by the Centers include human capital development (e.g., through informal and formal training) and institutional development.
4. As not-for-profit organizations with a global reputation for scientific excellence and political non-partisanship, the Centers are uniquely placed to play an important role in facilitating links between organizations with highly diverse objectives and operating philosophies (e.g., NAROs, ARIs, private firms and NGOs). Thus the Centers are working to build innovative research partnerships that will help to speed the flow of technology from the North to the South.

9.2 Future Role of the Centers

With time, biotechnology research within the Centers will mature, and biotechnology methods will become more seamlessly integrated into the Centers' conventional germplasm improvement programs. Similarly, biotechnology research programs in developing countries will strengthen and consolidate. As this process unfolds, attention will gradually shift from technical research problems to the challenge of moving products out of the laboratory and into farmers' fields.

The expected shift in focus from research and capacity-building activities to technology transfer activities has a number of implications for the future role of the CGIAR Centers:

1. As biotechnology is assimilated into the research programs of the Centers and into those of their national program partners, the Centers will have to direct increased attention to the design and implementation of regulatory systems for assessing the safety of biotechnology research procedures and for monitoring the deployment of products developed using biotechnology, particularly transgenic plants and animals.
2. As germplasm improvement methods become increasingly sophisticated, the CGIAR Centers will have an important role to play in educating the public about the technical aspects of biotechnology, as well as about the

potential benefits and costs of products developed using biotechnology. Technologies such as genetic engineering that are allowing scientists to redesign the basic blueprints for many plant and animal species have engendered concerns among the public that will be resolved only when sufficient information is available to allow people to make informed judgments and decide for themselves.

3. If the CGIAR is to remain influential in the global research arena, the Centers will have to adapt to the realities of the changing environment in which science is carried out. With the accelerating privatization of science, the traditional model of public research organizations subsisting entirely on government funding and distributing their products free of charge will become obsolete. Public investment in research will still be justified to address the technology needs of disadvantaged groups, but it is unlikely that the Centers will be able to continue to operate on a non-commercial basis, isolated from the private firms that account for an increasing proportion of overall research investment and control more and more of the new technologies. If the Centers are to continue to pursue their mandate to serve the poor in developing countries, they will have to learn how to collaborate effectively with a much wider range of partners in an environment that will become increasingly market-driven. This will mean acting less like old-style public research organizations and more like market-oriented private firms.
4. The need to devote increased attention to technology transfer and deployment will not absolve the CGIAR Centers of their traditional responsibility to conduct research. On the contrary, if they are to maintain a significant presence in the global research arena, the Centers will have to move aggressively into new areas of science. Work now being done in functional genomics and proteomics is rapidly expanding our understanding of how genes work. The Centers must position themselves to take full advantage of these and other innovations. Partnerships will enable them to access some new technology, but in cases in which technology will not be available from third parties, the Centers will have to continue to do original cutting-edge research.

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REFERENCES

Alvarez-Morales, A. (1999): Finding a Formula to Ensure the Safety of the Environment While Benefiting from Biotechnology. Paper presented at the CGIAR-NAS conference "Ensuring Food Security, Protecting the Environment, and Reducing Poverty in Developing Countries: Can Biotechnology Help?", 21-22 October, Washington, D.C.

Anderson, J.R., and D.G. Dalrymple (1999): The World Bank, the Grant Program, and the CGIAR: A Retrospective Review. OED Working Paper Series, No. 1, World Bank, Washington, D.C.

Barton, J.H., and W.E. Siebeck (1992): Intellectual Property Issues for the International Agricultural Research Centers. Issues in Agriculture 4, Consultative Group on International Agricultural Research, Washington, D.C.

CGIAR (1998a): Report of the CGIAR Panel on General Issues in Biotechnology. Prepared for the CGIAR mid-term meeting, 25-29 May, Consultative Group on International Agricultural Research, Brasilia.

CGIAR (1998b): Report of the CGIAR Expert Panel on Proprietary Science and Technology. Prepared for the CGIAR mid-term meeting, 25-29 May, Consultative Group on International Agricultural Research, Brasilia.

CGIAR (1997): Added Information on Expenditures in Biotechnology in 1997. Note prepared by the TAC Chairman for the discussions on biotechnology, International Centers Week, Consultative Group on International Agricultural Research, Washington, D.C.

Cohen, J.I., C. Falconi, J. Komen, and M. Blakeney (1998): Proprietary Biotechnology Inputs and International Agricultural Research. ISNAR Briefing Paper, No. 39. International Service for National Agricultural Research, The Hague.

Cohen, J.I. (1999): Managing Intellectual Property – Challenges and Responses for Agricultural Research Institutes. Paper presented at the CGIAR-NAS conference "Ensuring Food Security, Protecting the Environment, and Reducing Poverty in Developing Countries: Can Biotechnology Help?", 21-22 October, Washington, D.C.

Evenson, R. (1999): The IAEG Crop Germplasm Impacts Study: A Provisional Report. Paper presented at International Centers Week, Consultative Group on International Agricultural Research, Washington, D.C.

Falconi, C. (1999): Agricultural Biotechnology Research Indicators In Developing Countries. Paper presented at the conference "The Shape of the Coming Agricultural Biotechnology Transformation", 17-19 June, Tor Vergata University, Rome.

Fuglie, K., N. Ballenger, K. Day, C. Klotz, M. Ollinger, J. Reilly, U. Vasavada, and J. Yee (1996): Agricultural Research and Development: Public and Private Investments under Alternative Markets and Institutions. AER No. 735, Economic Research Service, United States Department of Agriculture, Washington, D.C.

Lewis, J., and A. Johanson (1999): The Role of Biotechnology Policies and Regulations in Technology Transfer to Developing Countries. Paper presented at the conference "The Shape of the Coming Agricultural Biotechnology Transformation", 17-19 June, Tor Vergata University, Rome.

Maredia, M., D. Byerlee, and K. Maredia (1999): Investment Strategies for Biotechnology in Emerging Research Systems. Paper presented at the conference "The Shape of the Coming Agricultural Biotechnology Transformation", 17-19 June, Tor Vergata University, Rome.

Pinstrup-Andersen, P. (1999): Biotech and the Poor. *Washington Post*, 27 October, p.31.

Plucknett, D., J.I. Cohen, and M.E. Horne (1990): Role of the International Agricultural Research Centres. In: G.J. Persley (ed.). *Agricultural Biotechnology: Opportunities for International Development*. CAB International, Wallingford, UK.

Sederoff, R., with L. Meagher (1995): Access to Intellectual Property in Biotechnology: Constraints on the Research Enterprise. In: J.E. MacDonald (ed.). *Genes for the Future: Discovery, Ownership, Access*. NABC Report 7. National Agricultural Biotechnology Council, Ithaca, NY.

APPENDIX A

Table A 1: CGIAR Centers – summary data

Center	Full name	Year founded	Headquarters location	Main focus of biotechnology work
CIAT	Centro Internacional de Agricultura Tropical	1967	Cali, Colombia	Cassava, beans, rice
CIFOR	Center for International Forestry Research	1993	Bogor, Indonesia	Forestry
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo	1966	Mexico City, Mexico	Maize, wheat
CIP	Centro Internacional de la Papa	1970	Lima, Peru	Potato, sweetpotato
ICARDA	International Center for Agricultural Research in the Dry Areas	1975	Aleppo, Syria	Barley, wheat, lentil
ICLARM	International Center for Living Aquatic Resources Management	1977	Penang, Malaysia	Aquatic resources
ICRAF	International Center for Research in Agroforestry	1977	Nairobi, Kenya	Agroforestry
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics	1972	Patancheru, India	Sorghum, millet
IFPRI	International Food Policy Research Institute	1978	Washington, DC, USA	Food policy
IWMI	International Water Management Institute	1984	Colombo, Sri Lanka	Water management
IITA	International Institute of Tropical Agriculture	1967	Ibadan, Nigeria	Cassava, maize, rice
ILRI	International Livestock Research Institute	1973 [a]	Nairobi, Kenya	Livestock systems
IPGRI	International Plant Genetic Resources Institute	1974	Rome, Italy	Genetic resources
IRRI	International Rice Research Institute	1960	Los Baños, Philippines	Rice
ISNAR	International Service for National Agricultural Research	1980	The Hague, Netherlands	Research systems
WARDA	West Africa Rice Development Association	1970	Bouake, Côte d'Ivoire	Rice

a. Established in 1995 following merger of International Livestock Centre for Africa (1974) and International Laboratory for Research on Animal Diseases (1973).

Table A 2: CGIAR investment in biotechnology research, late 1990s

	CIAT	CIMMYT	CIP	ICARDA	ICRAF	ICRISAT	IFPRI
Biotechnology research started	1985	mid-1980s	early 1980s	1990	1995	mid-1980s	1997
Biotechnology investment							
Biotechnology research budget (thousand US$)	2,200	3,000	1,500 [a]	1,000	110	1,650	300
Total center budget (thousand US$)	30,000	35,400	22,900 [a]	27,630 [f]	23,000	22,000	23,800
Biotech research/total center budget (percent)	7.3	8.5	6.6 [a]	3.6	0.5	7.5	1.3
Biotechnology personnel							
Senior scientific staff (full-time equivalents)	10	15	7.5 [b]	6.5	0.4	6.75	1.5
Support staff (full-time equivalents)	n.a.	50	n.a.	10	1.3	n.a.	1.3
Research activities							
DNA fingerprinting/genetic diversity studies	Yes	Yes	Yes	Yes	Yes	Yes	No
Gene mapping – quantitative and qualitative	Yes	Yes	Yes	Yes	No	Yes	No
Gene discovery (ESTs, reverse genetics)	Yes	Yes	Yes	No	No	Yes	No
Tissue culture (micro-propagation, embryo rescue)	Yes	Yes	Yes	Yes	No	Yes	No
Genetic engineering/transformation	Yes	Yes	Yes	Yes	No	Yes	No
Pathogen detection – ELISA, PCR	Yes	Yes	Yes	Yes	No	Yes	No
Vaccine development	No	No	No	No	No	No	No
Other	Yes [d]	Yes [e]	No	No	No	No	Yes [e]

Table A 2 (continued): CGIAR investment in biotechnology research, late 1990s

	IITA	ILRI	IPGRI	IRRI	ISNAR	WARDA	Total
Biotechnology research started	1980	1979	1974	1980	1993	late 1990s	
Biotechnology investment							
Biotechnology research budget (thousand US$)	1,540	6,500	2,150 [c]	4,000	850	180	24,980
Total center budget (thousand US$)	33,830	28,000	23,000 [c]	34,500	9,500	11,800	325,360
Biotech research/total center budget (percent)	4.6	23.2	9.3 [c]	11.6	8.9	1.5	7.7
Biotechnology personnel							
Senior scientific staff (full-time equivalents)	5.8	20	17	8	4	2	> 104
Support staff (full-time equivalents)	27	100	11	20	1.5	4	> 224
Research activities							
DNA fingerprinting/genetic diversity studies	Yes	Yes	Yes	Yes	No	Yes	
Gene mapping – quantitative and qualitative	Yes	Yes	Yes	Yes	No	Yes	
Gene discovery (ESTs, reverse genetics)	Yes	Yes	Yes	Yes	No	No	
Tissue culture (micro-propagation, embryo rescue)	Yes	Yes	Yes	Yes	No	Yes	
Genetic engineering/transformation	Yes	Yes	Yes	Yes	No	No	
Pathogen detection – ELISA, PCR	Yes	Yes	Yes	Yes	No	Yes	
Vaccine development	No	Yes	No	No	No	No	
Other	Yes	No	Yes [e]	Yes [e]	Yes [g]	No	

Notes: All data are for 1999 unless otherwise noted. n.a. means not available

a. 1995 data.
b. 1996 data.
c. 1997 data.
d. Research on micro-nutrients and vitamins.
e. Policy research.
f. 1997 operating expenses, including a US $4,283,0000 deficit.
g. Policy research and managing biotechnology.

Sources: CIMMYT survey, CGIAR (1997), CGIAR web site.

APPENDIX B: CGIAR CENTERS' POSITION STATEMENT ON BIOTECHNOLOGY

Given the immensity of the long-term food security and environmental conservation challenges confronting countries of the South, the Centers firmly believe in the following propositions:

- Biotechnology must be viewed as one of the critical tools for providing food security for the poor.
- The Centers advocate the prudent application of the full range of biotechnology tools to achieve substantial and sustainable growth in agricultural productivity in poor countries. These tools include, but are not limited to, molecular markers, genetic engineering, and recombinant vaccines.
- The Centers view biotechnology as an essential means for ensuring environmental protection over the long term.
- The Centers have a clear comparative advantage in ensuring access by the countries of the South to the advanced tools of biotechnology. This advantage accrues by virtue of the Centers' present credible mass in biotechnology, their global network of partnerships within and among countries of the South, and their increasingly close linkages to advanced research institutes (ARIs) of the North, both public and private.
- Given the extremely rapid pace of new developments in biotechnology, the Centers are committed to increasing their partnerships with ARIs, both public and private, North and South, to ensure ready access of Center scientists and our partners in the South to advanced technologies.
- The Centers make adequate investments in the arena of biotechnology in order to: 1) maintain their own credible scientific mass; 2) be proactive in assisting countries of the South to establish effective biosafety regulations; and 3) contribute substantially to developing the human capital needed to ensure the judicious application of appropriate biotechnology tools to important food security and environmental problems.
- The Centers are firmly committed to the application of genomics (molecular genetics, molecular markers) for immediate use in better understanding and manipulating the genomes of plants, animals, and their pathogens and pests.
- The development and deployment of transgenics (via genetic engineering) is seen by the Centers to provide important options for meeting the food security and environmental challenges of the future.
- The Centers will carry out all of their activities in the arena of biotechnology under high standards of appropriate and approved biosafety regulatory frameworks, both within individual countries and institutions. The Centers will seek partnerships with institutes that have such frameworks in place (thus our commitment to policy and capacity-building in this area).

Chapter 21

THE ROLE OF NATIONAL AGRICULTURAL RESEARCH SYSTEMS IN PROVIDING BIOTECHNOLOGY ACCESS TO THE POOR: GRASSROOTS FOR AN IVORY TOWER?

Willem Janssen, Cesar Falconi, and John Komen

Abstract: This paper reviews the role of national agricultural research systems (NARSs) in providing biotechnology access to the poor and examines the possibilities for enhancing this role. Recent surveys in different developing countries suggest that the share of biotechnology research in total agricultural research increased in recent years. However, the overall biotechnology capacity is still far below that of developed countries. Furthermore, biotechnology is often associated with upstream strategic research, and there is the risk that this will always remain within the "ivory tower". NARSs facilitate biotechnology access to the poor by supporting the development of an adequate regulatory framework and by undertaking research. Integrating biotechnology in problem-oriented, multidisciplinary research – where possible in collaboration with private-sector companies – is the best way to reach the poor. Five strategic activities are proposed to enhance the role of NARSs: priority setting, policy development, research management capacity development, technology transfer and international collaboration.

1 INTRODUCTION

Agricultural biotechnology can overcome production and post-harvest constraints that cannot be addressed with traditional research means. It is gradually being applied to solve practical production or post-harvest issues and to improve the efficiency of more traditional research approaches, especially in more developed countries. In the USA, 35 percent of the corn crop, 55 percent of the soybean crop, and 50 percent of the cotton crop

M. Qaim et al. (eds.),
Agricultural Biotechnology in Developing Countries: Towards Optimizing the Benefits for the Poor, 357–380.

consisted of genetically modified materials in 1999 (OECD, 1999). Genetic markers and tissue culture techniques are also gaining importance in the agricultural research systems of developing countries (ISNAR/IITA, 1999), but there are not yet many cases of biotechnology research impacting the poor (for exceptions see Qaim 1998; Odame 1999).

Agricultural biotechnology inventions, especially those in the field of genetic modification, have been patented or protected more often than traditional research inventions. Because the benefits from biotechnology innovations can be appropriated in this way, the potential profits should attract the interest of the private sector. In fact, evidence from the United States bears this out: the private sector makes 70 percent of the investments in agricultural biotechnology (Fuglie et al., 1996) – as opposed to 54 percent of all agricultural research investments (USDA, 1999). On the other hand, the purchasing potential of developing countries, and especially of the poor, does not provide the same profit potentials as those in the USA or Western Europe. This suggests that the role of the public sector in agricultural biotechnology for developing countries should still be relatively large.

This paper examines what conditions are for biotechnology research in public national agricultural research systems (NARSs)[1] to contribute towards poverty alleviation in developing countries.[2] The role of the NARSs is analyzed in relation to the roles of other players, such as the private sector, international research centers and donors. Two questions will be answered in this paper:

- What is the role of the NARSs in agricultural biotechnology research for the poor?
- How can the role of the NARSs be made most effective?

The starting point of this paper is that biotechnology is often associated with advanced, upstream, basic or strategic research. Such research is often done more to strengthen the knowledge base of a country than to directly address production or marketing problems. To use a popular comparison, such research is often undertaken in an "ivory tower", far away from practical concerns. For biotechnology to benefit poor producers at the grassroots level, it must be able to affect their production and marketing

[1] People use the term "NARS" for many different concepts, ranging from "the public national agricultural research institute" to "all public and private organizations involved in agricultural research". Here it means "all public national organizations involved in agricultural research". This includes agricultural research institutes, universities, agricultural research councils and agricultural research units at more generally oriented institutes.

[2] Developing countries are highly diverse. In this paper we have not aimed to further specify the different types of developing countries. Our conclusions, therefore, do not refer to any specific country and may not be valid in every country. Rather, we highlight some of the more salient issues that will come up in the development process.

conditions; to benefit poor consumers, it must reduce the purchasing price of staple foods. The paper assesses whether present biotechnology research in the NARSs can achieve such impacts on poverty and what further changes may be useful.

We will lay out some of the more significant characteristics and developments in agricultural research systems because they will have major implications for the role of NARSs, and we will also review the present activities of NARSs in agricultural biotechnology. In focusing on providing biotechnology access to the poor, we will review first the role of NARSs in creating the conditions for biotechnology research through supporting regulatory activities. Next, attention will be given to the role of NARSs in building biotechnology capacity and in generating knowledge and technologies. Five strategic activities will be presented for enhancing the effectiveness of NARSs. Finally, we present our conclusions about the present and future roles of NARSs in focusing agricultural biotechnology on the needs of the poor. It will become clear that employing relatively advanced biotechnology tools for the specific concerns of the poor is a daunting challenge, but that certain options "to establish the ivory tower on grassroots" should be explored.

2 BIOTECHNOLOGY RESEARCH WITHIN NARSs

2.1 General Context

In most cases, agricultural biotechnology is a subset of the subjects that the NARS is concerned with. The potential of the NARS in the field of agricultural biotechnology is largely conditioned by the overall developments that the system is facing. Before focusing on biotechnology, it will be helpful to provide a brief analysis of the overall developments of NARSs. Table 1 provides data on public and private investments in agricultural research for a number of developing countries. There are three conspicuous issues:

1. The agricultural research intensity in developing countries is considerably below the levels of developed countries. But because of the size of the agricultural sector in the developing world, the overall public sector investment is slightly larger than in the developed world.
2. The size of private sector investments in comparison to public sector investments is small, but the public system is the principal source of research services for developing countries. In the selected countries, private investments amount to less than 25 percent of public

investments. The combined size (public and private) of the agricultural research system in the developed world is still considerably larger than in the developing world.

3. The share of universities within the public agricultural research system tends to be lower than in developed countries. Only in India does it amount to a third of the total system, and while this is the highest number, it is lower than the average for developed countries.

Agricultural research capacity in developing countries tends to be concentrated in a limited number of national research institutes, and this is also where most biotechnology research takes place. The growth of public agricultural research from 1971 to 1991 has been considerably higher in the developing than in the developed world (5.1 percent versus 2.3 percent per annum), and this has made public agricultural research spending larger than in the developed world.

Table 1: Public and private agricultural research spending in selected developing countries (1992)

Country	Public spending (million US$)	Agricultural research intensity [a]	University share (percent)	Private spending (million US$)
Argentina	83.0	0.76	5	7.8
Brazil	790.6	1.56	22	18.3
Chile	37.9	0.98	20	1.6
Colombia	47.7	0.45	2	27.1
Ecuador	10.0	0.27	5	6.9
Mexico	143.1	0.58	17	52.6
Peru	29.0	0.99	20	3.9
Venezuela	46.9	0.73	10	4.6
India	1,561.8	0.52	33	493.2
Zimbabwe	20.3	1.88	n.a.	8.7
Kenya	33.3	1.76	n.a.	5.9
All developing countries	8,009.0	0.50	n.a.	n.a.
All developed countries	7,168.5	2.80	43	7,008.5

Note: n.a. means not available.

a. The agricultural research intensity is defined as public agricultural research spending relative to the agricultural gross domestic product.

Sources: Cremers and Roseboom (1997), Echeverría et al. (1996), Beynon (1998), Pray and Umali-Deininger (1998), Tabor et al. (1998), ISNAR (various years).

After 1991, the funding pressure on most public research systems has increased strongly. Several factors are contributing:

- A disproportionate growth in personnel.
- An overall reduction of public spending in response to structural adjustment programs.
- Demand for research services that NARSs have not always responded to rapidly. This concerns especially environmental and agroindustrial demands.

Lately, the concept of the NARS itself has come under review. The central concern is whether present operations, which focus on generating technologies through research, are the most effective way of contributing to the development of the agricultural sector. Many wonder whether NARSs should take a more facilitating function, allying themselves more routinely with partner organizations, such as farmers' groups, private companies, other government agencies and non-governmental organizations (NGOs). This would allow them to focus on the importation and use of technologies from abroad and would create an environment that encourages innovation across the sector (Piñeiro, 1999). In these more open systems the NARSs would catalyze the generation of new technologies rather than being the (perceived) primary source of it (Brenner, 1997).

2.2 Biotechnology within the NARSs

Quantitative data on the use of biotechnology in developing countries are hard to find. To start filling in this gap, the International Service for National Agricultural Research (ISNAR) recently conducted a survey on agricultural biotechnology in the NARSs of Mexico, Kenya, Indonesia and Zimbabwe (Falconi, 1999). The survey sample covers the most relevant public and

Table 2: Number of agricultural biotechnology research organizations in selected countries (1997)

Country	Core activity	Support activity
Indonesia	3	5
Kenya	1	5
Mexico	3	11
Zimbabwe	1	5
Total	8	26

Sources: Moeljopawiro and Falconi (1999), Wafula and Falconi (1998), Qaim and Falconi (1998), Gopo and Falconi (1999).

Table 3: Distribution of agricultural biotechnology research expenditures by sector in selected countries (percent)

	Indonesia		Kenya		Mexico		Zimbabwe	
Sector	1989	1997	1985	1997	1989	1996	1989	1998
Public research institute	66	85	50	60	47	72	1	81
Public university	14	11	50	28	49	24	98	3
Private non-commercial	0	1	0	4	4	4	0	16
Private commercial	20	3	0	8	0	0	0	0
Total	100	100	100	100	100	100	100	100

Sources: Moeljopawiro and Falconi (1999), Wafula and Falconi (1998), Qaim and Falconi (1998), Gopo and Falconi (1999).

private organizations involved in agricultural biotechnology research.[3] Biotechnology is a core activity in nearly 25 percent of them (see Table 2). Four of the eight specialized research organizations only recently began their biotechnology research.

Table 3 shows the percentages of research expenditures in the various sectors of agricultural biotechnology research. Public-sector organizations accounted for 92 percent of research expenditures during the period of analysis. These data suggest that the share of private investment in biotechnology research is still below the average for agricultural research. The private sector, however, showed higher annual growth rates than the public sector (except for Indonesia). The universities even showed a significant decline in research expenditures, probably due to economic recession and a drop in donor funding. Financial resources are concentrated in only a few public research institutes: the Kenyan Agricultural Research Institute (KARI) (70 percent of total expenditures in 1996), The Biotechnology Research Institute (BRI) in Zimbabwe (80 percent in 1998), three research organizations in Indonesia (70 percent in 1997), and three Mexican research organizations (55 percent in 1997).

Between 1988 and 1997 the number of researchers in biotechnology at least doubled, while the number of PhDs at least tripled in all surveyed countries. This growth may be explained by the significant increase in the number of biotechnology postgraduate programs, the establishment of specialized research organizations that required more scientists trained in biotechnology, and special grant programs that encourage scientists to become involved in related research. During the period of analysis, the number of researchers in agricultural biotechnology in Kenya, Mexico and

[3] The data presented refer to both public and private sector activities in biotechnology research but allow for a clear distinction of the actual roles of NARSs and private sector.

Zimbabwe grew faster than the research expenditures (see Table 4). This resulted in a 7 percent annual decrease in expenditures per researcher.

Downer et al (1990) have suggested a minimum efficient size for research groups in agricultural biotechnology. For genetic engineering and tissue culture, a ratio of one researcher to two support personnel (technicians) was recommended. In the four countries, though, there is only one technician for every two researchers on average.[4] Most of the research organizations show a low technical support-to-researcher ratio, which could negatively affect the development of research outputs.

Table 4 also reveals that expenditures per researcher were higher in Mexico and Indonesia than in Kenya and Zimbabwe. This implies that Mexican and Indonesian researchers have more resources and are more likely to generate biotechnology research results. Indonesia was the only country that showed a significant annual growth in expenditures per researcher during the period of analysis. However, expenditures per researcher dropped in 1997 due to the beginning of the financial crisis in the country. All the research organizations showed negative annual growth in that year.

Biotechnology's share of total agricultural research expenditures has grown rapidly in three of the four countries: In 1997, it was around 2.8 percent for Kenya, 9.6 percent for Mexico, 9.6 percent for Indonesia, and 10.0 percent for Zimbabwe. In comparison, the Consultative Group on International Agricultural Research (CGIAR) spent about 8 percent of its

Table 4: Agricultural biotechnology research expenditures in selected countries

	Indonesia		Kenya		Mexico		Zimbabwe	
	1997	AG	1996	AG	1997	AG	1998	AG
Expenditures (million 1985 intern. dollars)	18.7	29.3	3.0	2.6	20.4	6.3	3.5	7.5
Expenditures (million nominal US$)	6.0	30.8	1.2	2.5	11.5	8.5	1.4	3.8
Exp. per researcher (thsd. 1985 intern. dollars)	53.6	13.7	45.5	-7.2	85.1	-6.4	43.0	-8.0
Exp. relative to total agr. research (percent)	9.6	24.1	2.8	-2.3	9.6	9.8	10.0	9.0

Note: AG means percentage annual growth over the period of analysis.

Sources: Moeljopawiro and Falconi (1999), Wafula and Falconi (1998), Qaim and Falconi (1998), Gopo and Falconi (1999).

[4] Technical support staff are those that directly assist in designing and conducting agricultural research activities. They include laboratory technicians and biometricians and usually have a post-secondary professional education.

budget on biotechnology research in 1997. Within the USA, 13 percent of public agricultural research expenditures were assigned to biotechnology in 1992, and an estimated 20 percent of the public and private expenditures together (Fuglie et al., 1996; Caswell et al., 1994; calculations by the authors).

Table 5 presents the funding sources for agricultural biotechnology research in the four countries. International donor funding has been important, especially in Africa. In the late 1990s, KARI accounted for nearly 85 percent of total biotechnology-related donor support in Kenya, and BRI for almost 90 percent in Zimbabwe. The sustainability of these levels of funding will be compromised in the medium term if there is no effort to obtain funding from national sources.

Private, non-commercial organizations fund their biotechnology research through contracts and levies, whereas commercial companies cover their research outlays mainly by product sales. In the public sector, except for donor funds, most of the funds come from the government. Although non-traditional funding sources, such as product sales, services and other contractual arrangements, increased during the period of analysis, their overall importance is still rather small. This phenomenon reveals how minimal the interaction is between public entities and the private sector. In a study of the poor interaction between these sectors in Mexico, Wagner (1998) concluded that (i) the private sector can import technology more cheaply, (ii) the government neglects the use of science to foster economic development, (iii) the regulatory framework confuses foreign and local companies in introducing biotechnology products, (iv) the basic research orientation of scientists impedes collaboration between scientists and businessmen, and (v) there is a lack of funding mechanisms to bring the two sectors closer to each other.

Table 5: Agricultural biotechnology funding sources in selected countries (percent)

Funding source	Indonesia (1997)	Kenya (1996)	Mexico (1997)	Zimbabwe (1998)
Government	93	28	60	34
Product sales	4	3	12	16
Contracts	1	0	4	0
Donors	2	67	24	50
Levies	0	2	0	0
Total	100	100	100	100

Sources: Moeljopawiro and Falconi (1999), Wafula and Falconi (1998), Qaim and Falconi (1998), Gopo and Falconi (1999).

Table 6: Agricultural biotechnology research techniques used in selected countries (percent of researchers)

	Indonesia (1997)		Kenya (1996)		Mexico (1997)		Zimbabwe (1998)	
Techniques	Public	Private	Public	Private	Public	Private	Public	Private
Tissue culture	40	90	76	100	68	90	66	67
Genetic engineering	60	10	24	0	32	10	34	33
Total	100	100	100	100	100	100	100	100

Sources: Moeljopawiro and Falconi (1999), Wafula and Falconi (1998), Qaim and Falconi (1998), Gopo and Falconi (1999).

The allocation of biotechnology resources to livestock seems low: the contribution of livestock to agricultural production was 50 percent in Kenya in 1996, 45 percent in Mexico in 1997, 30 percent in Indonesia in 1997, and 35 percent in Zimbabwe in 1998. In the institutes surveyed, the share of biotechnology efforts in livestock was 25 percent in Kenya, zero percent in Mexico, 10 percent in Indonesia, and 20 percent in Zimbabwe.

Tissue culture and genetic engineering techniques were used to position institutes within a spectrum of research techniques (see Table 6). In Mexico and Indonesia, 50 percent of the researchers are applying advanced techniques, such as genetic engineering. The other half uses less sophisticated techniques, such as tissue culture. In Kenya and Zimbabwe, 30 percent of the researchers use more advanced techniques, and 70 percent use less sophisticated biotechnology techniques. A significant proportion of public-organization researchers frequently uses less advanced techniques to complement advanced techniques. The public sector also applies biotechnology to "orphan commodities" and to solve problems of farmers in marginal agroecological locations.

At the request of the Rockefeller Foundation, another survey of public agricultural research organizations (including the universities) in nine African countries (Ethiopia, Kenya, Uganda, Malawi, South Africa, Zimbabwe, Cameroon, Ghana, Nigeria) was undertaken in 1998 by ISNAR and the International Institute for Tropical Agriculture (IITA) (ISNAR/IITA, 1999). The study confirms the findings of the earlier survey of research techniques for four countries: 47 percent of biotechnology research projects concern tissue culture (mainly for the purpose of producing virus-free planting material), 13 percent concern genetic engineering, 13 percent the use of genetic markers; 17 percent the development and use of disease diagnostic methods; and 9 percent microbiology. This survey also provided information on the crops to which biotechnology is applied (see Table 7).

Table 7: Target crops of biotechnology research projects in 10 African countries (1998)

Crops	No. of research projects	Percent
Cereals	44	19
Root and tubers	67	29
Legumes	21	9
Banana/plantain	21	9
Cash crops	22	10
Fruits and vegetables	29	13
Others (incl. forestry and ornamental crops)	26	11

Source: ISNAR/IITA (1999).

The most researched crop category are roots and tubers (including cassava, yam, sweetpotato and potato), followed by cereals (maize, sorghum, rice, others). Fruits and vegetables and cash crops came in third and fourth place, respectively.

Both surveys conclude that the more advanced biotechnology research in developing countries is concentrated in the public sector. The private sector tends to emphasize tissue culture, especially for the micropropagation of clean planting material. Although tissue culture techniques also dominate public sector biotechnology research, the public organizations are often also acquainted with more complex biotechnology methods. The focus in public plant biotechnology is on roots, tubers and cereals, all of which are crops of high importance to the poor in the developing world. The development of biotechnology research capacity is still in its initial phase, vulnerable to funding shocks, dependent on external funding and often driven by the preferred directions of the national pioneer scientists. The public sector is leading this process in developing countries; the share of biotechnology in total research expenditures is comparable with the CGIAR system, and not far away from the USA. But because of the low overall research intensities and limited private sector participation, a sizeable gap exists in the biotechnology research capacity of developed and developing countries.

3 MAKING BIOTECHNOLOGY WORK FOR THE POOR: CHALLENGES FOR THE NARSs

Due to new insights about innovation and the pressures created by structural adjustment policies, the role of the public sector in society has been under scrutiny in many countries (Tabor, 1995). Legislation and regulation are commonly seen as public responsibilities, and regulation is increasingly seen as an activity that creates the conditions for widespread innovation. In reforming research systems in the developed world, the contribution of NARSs to regulatory processes has acquired significant importance (Janssen, 1999). Providing research goods that are freely accessible to all people is also a responsibility of NARSs, but ideas about what should be freely accessible are gradually changing. The role of the NARSs in providing biotechnology access to the poor must be reviewed from both the perspective of regulation and the perspective of providing public research goods.

3.1 The Role of NARSs in Regulatory Processes

Adequate regulation requires several steps:

- the existence of adequate norms and standards;
- the conversion of these norms and standards into clear and unambiguous rules; and
- the effective enforcement of these rules.

NARSs have a role to play in defining the adequate technical norms and standards for agricultural biotechnology. In fact, in most developing countries there are not many other organizations that have the required skills and knowledge to define norms or to interpret the relevance of norms from abroad. But the effectiveness of the NARSs in this field depends upon partners in the public sector to take care of the second and third steps. This requires the involvement of law-makers (parliament at the highest level, but also ministries) and law enforcement agencies. Regulation thus requires public sector partnerships. Three issues are central in biotechnology regulatory policies:

1. *Biosafety concerns.* A principal concern about the testing or release of genetically engineered materials is the possibility of genetic interchange. Some of the traits transferred by genetic engineering might allow non-cultivated species to compete successfully with the cultivated species. Other concerns are the possibility of virus recombination leading to new unknown diseases, the build-up of pest-resistance, and the effects of genetically modified products on non-targeted species (e.g., butterflies). The environmental risks in biotechnology research and biotechnology-based agriculture need to be understood and managed at a level acceptable to the country. Whereas the biotechnology capacity of most developing countries is centered on tissue culture, many international companies want to sell genetically modified seeds. Biosafety concerns would thus tend to lie as much in the distribution of commercial materials as in research protocols. Biosafety regulation has to be based

on a sound scientific understanding of the possible risks. It requires skilled and dedicated people, and also concerns sectors beyond agriculture, such as health, environment and manufacturing. The prime concern of the NARSs in biosafety is not just to operate on the safe side of the norms but also to create the right enabling environment for all the actors somehow involved in biotechnology.

2. *Food quality and safety concerns.* The poor in the developing world benefit greatly from new technologies through reduced food prices. But this will only be true if price reductions are not achieved at a disproportionate expense in food quality and food safety. In a liberalized world economy, food imports (and exports) tend to increase, and developing countries may need food standards in addition to agricultural production standards. With the growing range of genetically modified crops being used in food products, a public debate has evolved regarding its implications for human health. Although the debate largely takes place in Europe and the USA, it will likely appear in developing countries as well (Tripp, 1999). The outcome remains to be seen: price reductions might or might not weigh more heavily in the perception of poor consumers than foodsafety concerns. Policy implications should be drawn, however, on the basis of good information. NARSs have a role to play in making this information available and, as is the case with biosafety, in contributing to the creation of enabling regulations.
3. *Intellectual property rights.* Developing and enforcing intellectual property right (IPR) legislation is commonly assumed to encourage private-sector involvement in the generation of new technologies (Brenner, 1998). Strengthening IPRs for biological products and processes in developed countries has facilitated private-sector investment in biotechnology research. As a result, technology users, including those in developing countries, increasingly have to pay for the right to use given procedures or products. This can involve complex ownership issues and have important implications for access to products, trade and investment. Cooperation between the public and private sectors also requires clear, mutually agreed upon rules and guiding principles for IPRs. As shown in Table 8, the legal protection in most developing countries is considerably weaker than in developed countries. This disparity is often cited as a reason for the low levels of private investments. In terms of IPRs, the role of NARSs is concentrated in plant breeders' rights and seed certification mechanisms. Other issues in this field are of a legal nature and concern innovation in general, requiring expertise that is probably better found outside the NARSs.

Table 8: Trends in the Ginarte and Park index of patent rights (1960-90)

	1960	1970	1980	1990
OECD countries	2.71	3.01	3.36	3.47
Developing countries	1.99	2.09	2.16	2.21

Note: The index is made up of five components: extent of patent coverage; membership in international agreements; provisions for loss of protection; enforcement mechanisms; duration of protection: 0 = no protection at all; 5 = maximum protection in all five components.

Source: Ginarte and Park (1997).

The involvement of the NARSs in regulatory activities can be focused on the poor by giving more and rapid attention to products that are relevant to the poor. Food quality and foodsafety research should be done first on commodities primarily consumed by poor consumers. For biosafety concerns, regulation would be somewhat more generic, but for commodity specific issues it would again be reasonable to first develop norms and standards for products produced and consumed by the poor. IPRs are normally generic and do not allow for a targeted emphasis, but seed certification norms could first be developed for staple foods.

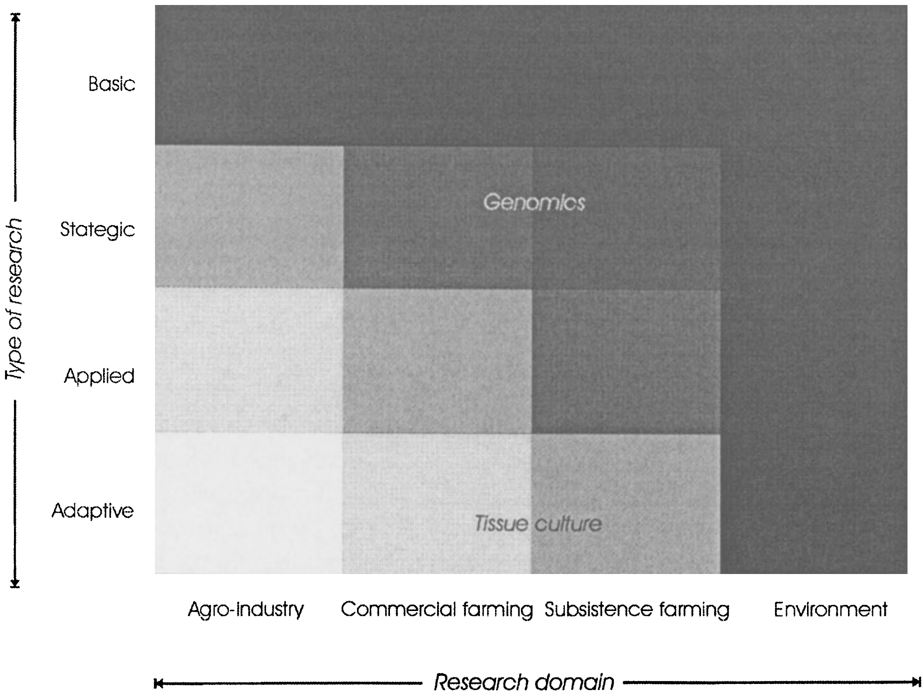
Another role, though not strictly regulatory, would be lobbying for the poor's preferential access to protected food crop varieties or other important biotechnology innovations. NARSs might persuade commercial companies to forego their property rights. Such a policy might encourage technological change in the short run, although if it were to eliminate incentives for varietal diffusion by local companies it would reduce local innovation in the long run.

The relative attention that NARSs should give to regulatory activities is another important question. Some authors argue that the lack of regulations is a principal cause of the low private investment levels in agricultural biotechnology. Overcoming these constraints, they believe, would trigger large private investments in agricultural research. But the absence of the private sector is actually caused primarily by the limited market potential for biotechnology products in developing countries and by the limited capacity of these countries for contracting or engaging in advanced science. The poor have very little market potential, and with the possible exception of foodsafety regulations, their fate is hardly defined by the existence of a clear regulatory framework. In addition, effective regulation requires enforcement, an element that may well be more constraining than the absence of clear norms and standards. Building accessible research capacity to encourage private sector involvement could be the prime role of NARSs, although one should not expect this to lead to great impacts on the poor. Given their interdependencies with other parts of the public sector, the NARSs might leave the initiation of regulations to other agencies (e.g., the National Biosafety Committee, the National IPR office), assisting as a constructive partner but concentrating on developing more research capacity within the country.

3.2 The Role of NARSs in Research and Technology Generation

Figure 1 provides a schematic overview in two dimensions that may help to define the role of NARSs in biotechnology research for the poor. First, it indicates that the importance of public research tends to be defined according to research type. Basic research is fundamental to advances in biotechnology, yet its outcome, duration and beneficiaries are difficult to predict. Furthermore, the knowledge produced belongs to the public domain. On the other hand, adaptive research normally addresses a clearly defined problem, has a clear target clientele, and is more amenable to private

Figure 1: The relevance of public agricultural research as defined by type of research and research domain



Note: Increasing degree of dark shading indicates growing relevance of public research.

investment. Second, it indicates the importance of the domain of research. For large agroindustries, the beneficiaries are often small in number, receive sizable benefits (in comparison with the research expenses), and are able to afford the costs of research. For small-scale subsistence farming, there are many beneficiaries, they receive limited benefits, and it is more difficult for them to afford the research. As a result, in the agroindustry domain, research can either be more easily financed privately by the users, or new technologies can be marketed to the sector. In the small farm sector, the capacity of the users to finance research is limited, the potential to market new technologies is more constrained, and the importance of public funding is larger.

For biotechnology research in the developed world, the possibility of taking out IPRs is creating a situation in which even basic research may be attractive to private companies. Still, the public sector's involvement in basic biotechnology research remains relevant mainly for four reasons: (i) the public sector must be part of advancing the technology frontier; (ii) it continues to support biotechnology education programs; (iii) it seeks to create public-domain alternatives to avoid possible abuse if control over biotechnology is fully privatized; (iv) it applies biotechnology to non-commercial problems of public importance (e.g., the environment).

The biotechnology activities in the developing country NARSs traditionally begin with plant tissue culture. This can remain their primary focus until more advanced capacity is developed. Targeting tissue culture to the poor is a matter of choosing the right type of commodity. The evidence from the ISNAR/IITA survey suggests that the African NARSs are giving considerable attention to crops for the poor. On the other hand, more advanced biotechnology research, such as genomic studies, remains far too advanced for most NARSs to undertake. Genomic studies increase the amount of available and useful information about the genetic structure of a certain organism; their outcomes may be used in many different ways. IPRs can turn genomic studies on mapping into a privately attractive activity, if the identified genes are relevant to high-value and high-volume seed markets. For many important crops in the developing world, such seed markets are not yet available, and this leaves the responsibility for research to the public sector. Carefully targeting appropriate crops and appropriate traits is one way that NARSs can direct the benefits of biotechnology to the poor.

Most NARSs, however, are not exclusively concerned with poverty. Support to export commodities also has a high political priority, because this is a field where private sector involvement can be expected if suitable public sector groundwork is available. When decision-making is uninfluenced by foreign donor requirements, investments in biotechnology for export crops may be a safer bet for NARSs than a focus on poverty.

Figure 1 may also suggest why agricultural biotechnology in developing countries is not taking off as quickly as anticipated. Many of the tools in biotechnology (e.g., genomics, genetic engineering) support strategic rather than adaptive research (tissue culture is more applied and in this respect is the exception to the rule). In general, the NARSs in developing countries, as well as private sector research initiatives, are geared towards more applied and adaptive types of agricultural research because the expected pay-off is more immediate.

Research leads to technologies that can be applied in one domain or another, to knowledge generation and to capacity development. Among many development thinkers, knowledge is increasingly seen as the most important factor for defining the competitive ability and growth potential of a nation. The development of a dense knowledge infrastructure, therefore, is an important strategy for any poor country in its efforts to improve the well-being of its citizens. In an incipient field like biotechnology, knowledge generation and capacity building are very important (Braunschweig and Janssen, 1999). The types of techniques that a country or institute wants to employ must be selected, mechanisms established to allow the use of the developed capacity across the sector, and procedures put in place to transfer skills to those who urgently need them. In the initial phases of development a major contribution of biotechnology to poverty alleviation will be indirect: it will establish a knowledge base in the agricultural sector that will allow faster technological progress in the future.

3.3 Enhancing the Role of NARSs in Biotechnology Research

Adapting the framework of Cohen et al. (1999), five strategic activities are proposed to enhance the role of NARSs in biotechnology research:

(1) Priority Setting

Through this activity NARSs establish their poverty orientation. Choosing research lines and topics that effectively combine such variables as economic efficiency, poverty alleviation, and capacity building is challenging. Importantly, however, this process contributes to explicitly expressing what an individual NARS wants to achieve and what constraints it faces. ISNAR has been adapting a priority setting approach based on the Analytic Hierarchy Process (AHP) that combines the multiple objectives of biotechnology research, the uncertainty associated with investments in a new field and the multi-institutional nature of most NARSs (Braunschweig and Janssen, 1998). AHP is able to incorporate poverty concerns, but whether this radically changes the list of priority subjects is uncertain. Byerlee (1999) shows that a Pakistan poverty-based research portfolio provides only 5 percent more benefits to the poor than an efficiency portfolio.

(2) Developing National Policies

Regulatory policies have been discussed earlier in this paper. Another national policy consideration is the location of biotechnology research capacity, whether in universities or in research institutes. For more strategic biotechnology research, universities may have the advantage because they are oriented more towards knowledge than technology and also combine research with the education of students, thus transferring important skills. On the other hand, the national agricultural research institutes are normally more concerned with technologies than with knowledge. And insofar as they collaborate with agencies or companies that can take care of the diffusion process, they provide a better location for adaptive techniques such as tissue culture.

Significantly, however, the biotechnology survey data for the four countries, and the African NARS data presented earlier, suggest that universities play a minor role. One reason for this is that funding for agricultural research normally flows from the Ministry of Agriculture to the research institutes that it patronizes – not to the universities, which are normally linked to the Ministry of Science and Education. Competitive grant schemes might be one way to overcome such funding rigidities.

Linking agricultural biotechnology with biotechnology research in other sectors (health, environment, forestry and energy) is another way to enhance the effective development of biotechnology research capacity. Many of the techniques used in agriculture are also used or further developed in other sectors. As Hedley (1998) writes, "the science of productivity advances in agriculture is no longer exclusively within the domain of the agricultural sector". Agricultural biotechnology needs to be developed within the framework of an overall national biotechnology policy, and within such broad inter-sectoral policies, universities might again be better placed for developing biotechnology capacity than agricultural research institutes.

In summary, the development of advanced biotechnology capacity will be strongly favored by an inter-sectoral policy. Such advanced biotechnology capacity is by itself difficult to focus on specific problems. Still, emphasizing adaptive techniques that support the diffusion of new seeds or other inputs might enhance a focus on poverty. Focussing on adaptive techniques might bring benefits to the poor in the short run, but reduces the ability to develop sustainable biotechnology capacity (and therefore research impact on the poor) in the medium and long run.

(3) Developing Research and Research Management Capacity

Biotechnology research has other management requirements than traditional research. Special infrastructure and new laboratories must be built. People with specialized skills must be available. Institutional biosafety procedures must also be in place and effectively managed. Legal capacity may be required to manage joint ventures or to undertake contract research. Three issues are central in regard to such development. First, there is often a lack of qualified human resources in agricultural biotechnology as well as a lack of information about the opportunities for human resource development. Second, many biotechnology programs in developing countries do not have a long-term financial strategy. They depend primarily on one source of funding. Third, research results are poorly evaluated for their past and future impacts on the agricultural sector.

(4) Transfer of Technologies, Knowledge and Skills

The results of many biotechnology research efforts are integrated in tangible products or inputs (vaccines, diagnostic kits, disease-free planting material, biopesticides and transgenic plant varieties). Joint ventures between public research organizations and private commercial input suppliers are needed to successfully conclude the product development cycle and to start delivering products to the end-user. Still, the requirements for biotechnology in this respect are no different from more traditional agricultural research. And so policies for encouraging public-private joint ventures should not be geared to biotechnology research exclusively, but to agricultural research in general.

It is important to observe that most collaborations between NARSs and private companies initially embrace the transfer of research results rather than the joint execution of research programs. Private sector involvement in research is rather limited in most developing countries at the moment. Furthermore, in most developing countries, the present turnover of domestic agricultural input companies is too small to justify the maintenance of their own in-house research programs. However, in the process of agricultural development, the input intensity of the agricultural sector will certainly increase (Roseboom, 1999), and more opportunities for domestically based private companies will arise.

For the multinational private sector, the small size of most national markets in developing countries has not yet triggered major research programs. As far as large companies are concerned they might make progress more effectively on such strategic issues as genetic engineering from their base in developed countries. In fact, EMBRAPA, the national agricultural research institute from Brazil, has decided to establish a biotechnology research unit in the USA so that it can benefit from better access to knowledge and research facilities.

(5) International Collaboration and Technology Transfer

In a field where investment costs are substantial and many different skills and disciplines are involved, the incentives for developing countries to acquire new knowledge and technologies through international collaboration are high. In fact, most biotechnology work in developing countries is strongly based on the importation and adaptation of methodologies and knowledge from abroad. Developing collaborative projects with advanced research organizations, international centers and NARSs from other countries, is key to maximizing their returns on biotechnology investments.

International collaboration also contributes to regulatory capacity building. In many developing countries, the importation of advanced biotechnology products stimulated parallel efforts to establish and implement biosafety review systems. In fact, the presence of an effective biosafety system can become a condition for international collaboration and technology transfer. Donor-funded, international collaborative research programs often contain specific requirements for biosafety review before transfer can take place. In addition, international technology transfer is increasingly managed through contracts, material transfer agreements and licenses, and no longer through free, informal exchange. This is especially the case for biotechnology, since many of the products and technologies are protected as intellectual property. NARSs will have to become skilled at dealing with protected products and technologies, which will also contribute to national and institutional regulatory policies. Finally, many international organizations aiming at the international transfer of biotechnologies provide support for regulatory capacity building. This is usually achieved through the provision of expert advice, infrastructure support, workshops and training courses.

4 CONCLUSION

For some NARSs, biotechnology spending has reached an importance proportional to the CGIAR and not far below the public sector of the USA. A large part of this spending concerns investment: building laboratories, training staff, etc. The biotechnology research capacity of most NARSs is only now starting to be applied to the problems of the farming community and to reinforcing traditional research approaches.

Similar to overall agricultural research, NARSs are now facing some strategic choices. With respect to the orientation of biotechnology research, poverty alleviation is not the only direction that can be chosen. Support for export commodities and cash crops (normally not in the hands of the poor) may pay off more quickly and lead to more incentives for the private sector to become involved in biotechnology research. The total direct benefits to the country may also be higher in such a strategy. It is also a promising strategy in terms of catalyzing innovation processes in the agricultural sector and supporting broadly based technology generation and adaptation processes. The strategic choice between food crops or export crops is further complicated by the difficulty of understanding how these choices affect the biotechnology knowledge available. Most poor countries are aware that the development of the agricultural knowledge base and the ability to successfully focus on specific problems are highly linked. Focusing on the poor may produce higher social benefits (although, in general, the evidence is not extremely convincing), but the public sector will be more on its own. The multiplier effects of such an orientation within the economy will be smaller, and the reliance on external funds and externally funded organizations (e.g., NGOs) may be bigger in the short to medium term.

Regulation issues further complicate the strategic choices of NARSs. Proper regulation is a condition for the involvement of the private sector, but it is not certain whether it is the most binding condition: poor scientific capacity and purchasing potential are other factors that limit the private sector's interest. At the moment, some NARSs have limited involvement in advanced biotechnology techniques, for which foodsafety, biosafety and IPR issues are most urgent. Focusing on regulation issues and waiting for rules to be in place might help the international private sector to acquire new markets, but it will have less of an impact on the dynamics of domestic private research. Instead, it might cause hesitation in developing national capacity. Regulatory development should take place simultaneously with capacity and market development, not far ahead of it.

To create the conditions that will encourage the private sector's involvement, universities may have a more important role to play than they currently do. Universities could enter into collaborative research projects and use this experience in their education programs, thus increasing awareness about the potential of biotechnology and spreading knowledge about it. The capacity of universities and their interaction with the private sector could be directed through competitive grant schemes.

To specifically reach the poor, biotechnology research strategies are no different from agricultural research strategies in general. It is important to understand that most biotechnology research will reach farmers in the form of traditional inputs (i.e., seeds, fertilizers and pesticides). Integrating biotechnology with traditional research approaches will be very important (e.g., using marker methodologies to speed up breeding or tissue culture to improve germplasm multiplication). Such an integrated approach has the following advantages: biotechnology research will benefit from the successes and failures of the poverty focus in traditional agricultural research; the expertise developed to link poor farmers with traditional agricultural research (e.g., participatory approaches) can be tapped; and the incentives for the private sector to develop the input sector will be based on knowledge obtained with traditional and new tools.

Such integration has one more advantage: it will allow developing countries to start employing the available biotechnology research capacity on the basis of user demands – rather than on the perception and interest of biotechnology scientists (Janssen and Goldsworthy, 1996). In applied biotechnology research, incorporating a demand focus is a major challenge for those countries that have passed the initial investment phase, but it will increase the relevance of its biotechnology capacity and lead to its further growth. Evidence from other scientific disciplines suggests that this integration is most easily achieved by applying biotechnology within problem-oriented research programs or projects. The ivory tower can be founded on grassroots, but only if more traditional buildings surround it.

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REFERENCES

Beynon, J. (1998): *Financing the Future: Options for Agricultural Research and Extension in Sub-Saharan Africa*. Oxford Policy Management, Oxford, UK.

Braunschweig, T., and W. Janssen (1998): Establecimiento de Prioridades en la Investigación Biotecnológica Mediante el Proceso Jerárquico Analítico. Research Report, No. 14, International Service for National Agricultural Research, The Hague.

Braunschweig, T., and W. Janssen (1999): Incorporating the Strategic Component of Biotechnology in Public Sector Research Evaluation. Paper presented at the conference "The Shape of the Coming Agricultural Biotechnology Transformation," 17-19 June, Tor Vergata University, Rome.

Brenner, C. (1997): Biotechnology Policy for Developing Country Agriculture. Development Center Policy Brief, No. 14, Organization for Economic Cooperation and Development, Paris.

Brenner, C. (1998): Intellectual Property Rights and Technology Transfer in Developing Country Agriculture: Rhetoric and Reality. Development Center Technical Paper, No. 133, Organization for Economic Cooperation and Development, Paris.

Byerlee, D. (1999): Targeting Poverty Alleviation in Priority Setting in National Research Organizations: Theory and Practice. Paper presented at the workshop "Assessing the Impact of Research on Poverty Alleviation", organized by the International Center for Tropical Agriculture, 14-16 September, San José.

Caswell, M., K. Fuglie, and C. Klotz (1994): Agricultural Biotechnology: An Economic Perspective. Agricultural Economic Report, No. 687, United States Department of Agriculture, Washington, D.C.

Cohen, J., C. Falconi, and J. Komen (1999): Identifying Needs and Priorities: A Decision-Making Framework for Agricultural Biotechnology. In: J. Cohen (ed.). *Managing Agricultural Biotechnology: Addressing Research Program Needs and Policy Implications*. CAB International, Wallingford, UK, pp. 7-14.

Cremers, M., and H. Roseboom (1997): Investment Trends in Public Agricultural Research in Latin America. Mimeo., International Service for National Agricultural Research, The Hague.

Downer, R., E. Dumbroff, B. Glick, J. Pasternack, and K. Winter (1990): Guidelines for the Implementation and Introduction of Agrobiotechnology into Latin America and the Caribbean. Interamerican Institute for Cooperation in Agriculture, San José.

Echeverría, R., E. Trigo, and D. Byerlee (1996): Institutional Change and Effective Financing of Agricultural Research in Latin America. World Bank Technical Paper, No. 330, World Bank, Washington D.C.

Falconi, C. (1999): Agricultural Biotechnology Research Indicators and Managerial Considerations in Four Developing Countries. In: J. Cohen (ed.). *Managing Agricultural Biotechnology: Addressing Research Program Needs and Policy Implications*. CAB International, Wallingford, UK, pp. 24-37.

Fuglie, K., N. Ballenger, K. Day, C. Klotz, M. Ollinger, J. Reilly, U. Vasavada, and J. Yee (1996): Agricultural Research and Development: Public and Private Investments under Alternative Markets and Institutions. Agricultural Economic Report, No. 735, United States Department of Agriculture, Washington, D.C.

Ginarte, J.C., and W.G. Park (1997): Determinants of Patent Rights: A Cross-National Study. *Research Policy* 26 (3), pp. 283-301.

Gopo, J., and C. Falconi (1999): Agricultural Biotechnology Research Indicators: Zimbabwe. Discussion Paper, No. 99-8, International Service for National Agricultural Research, The Hague.

Hedley, D. (1998): Global Challenges: Local Issues. Paper presented at the conference of the Association of Agricultural Economists of South Africa. 30 September to 2 October, Swakopmund, Namibia.

ISNAR (various years): ISNAR Indicator Series on Agricultural Research Investment in Developing Countries. International Service for National Agricultural Research, The Hague.

ISNAR/IITA (1999): Biotechnology for African Crops. Study commissioned by the Rockefeller Foundation, International Service for National Agricultural Research, International Institute for Tropical Agriculture, The Hague.

Janssen, W. (1999): Tendencias en la Organización y el Financiamiento de la Investigación Agrícola en los Países Desarrollados. Mimeo., PROCISUR, Montevideo.

Janssen, W., and P.R. Goldsworthy (1996): Multidisciplinary Research for Natural Resource Management: Conceptual and Practical Implications. *Agricultural Systems* 51, pp. 259-281.

Moeljopawiro, S., and C. Falconi (1999): Agricultural Biotechnology Research Indicators: Indonesia. Discussion Paper, No. 99-7, International Service for National Agricultural Research, The Hague.

Odame, H. (1999): Smallholders' Access to Biotechnology: The Case of Rhizobium Inocula in Kenya. Paper presented at the conference "The Shape of the Coming Agricultural Biotechnology Transformation", 17-19 June, Tor Vergata University, Rome.

OECD (1999): Modern Biotechnology and the OECD. Policy Brief, Organization for Economic Development and Cooperation, Paris.

Piñeiro, M. (1999): El Desarrollo del Sector Agrícola y las Demandas Tecnologicas. In: W. Janssen and J. Tola (eds.). *Integración de Demandas Agroindustriales y Ambientales en la Investigación Agrícola para el Siglo 21*. International Service for National Agricultural Research, The Hague.

Pray, C., and D. Umali-Deininger (1998): The Private Sector in Agricultural Research Systems: Will it Fill the Gap? *World Development* 26 (6), pp. 1127-1148.

Qaim, M. (1998): Transgenic Virus Resistant Potatoes in Mexico: Potential Socioeconomic Implications of North-South Biotechnology Transfer. ISAAA Briefs, No. 7, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

Qaim, M., and C. Falconi (1998): Agricultural Biotechnology Research Indicators: Mexico. Discussion Paper, No. 98-20, International Service for National Agricultural Research, The Hague.

Roseboom, H. (1999): Transformación Estructural del Sector Agrícola: Implicaciones para la Innovación Tecnológica. In: W. Janssen, and J. Tola (eds.). *Integración de Demandas Agroindustriales y Ambientales en la Investigación*

Agrícola para el Siglo 21. International Service for National Agricultural Research, The Hague.

Tabor, S. (ed.) (1995): Agricultural Research in an Era of Adjustment: Policies, Institutions and Progress. EDI Seminar Series, Economic Development Institute, World Bank, Washington, D.C.

Tabor, S., W. Janssen, and H. Bruneau. (eds.) (1998): *Financing Agricultural Research: A Sourcebook*. International Service for National Agricultural Research, The Hague.

Tripp, R. (1999): The Debate on Genetically Modified Organisms: Relevance for the South. In: J. Cohen (ed.). *Managing Agricultural Biotechnology: Addressing Research Program Needs and Policy Implications*. CAB International, Wallingford, UK, pp. 15-23.

USDA (1999): Agricultural Technology Development. AREI-Report 1999, United States Department of Agriculture, Washington, D.C.

Wafula, J., and C. Falconi (1998): Agricultural Biotechnology Research Indicators: Kenya. Discussion Paper, No. 98-14, International Service for National Agricultural Research, The Hague.

Wagner, C. (1998): Biotechnology in Mexico: Placing Science in the Service of Business. *Technology in Society* 20, pp. 61-73.

Chapter 22

AGRICULTURAL BIOTECHNOLOGY AND THE POOR: THE ROLE OF DEVELOPMENT ASSISTANCE AGENCIES

Gesa Horstkotte-Wesseler and Derek Byerlee

Abstract: This paper reviews the funding mechanisms for agricultural biotechnology and the current funding strategies of selected development assistance agencies. After examining the objectives and constraints of donors, options are discussed for enhancing their roles in biotechnology research and development (R&D) for the poor. If developing countries want to avail themselves of biotechnology's promise, they clearly need to integrate it within their own innovation systems. This should be done in accordance with their own priorities, through partnerships with advanced research institutes, private companies and regional cooperation. They need to build capacities not only in biotechnology R&D but also in associated regulatory and policy frameworks designed to ensure safe and efficient technology use. This will require strong public-sector support, both from developing-country governments and from donors, who have played a major role in developing agricultural R&D capacity in these countries over the past four decades.

1 INTRODUCTION

Biotechnology has much potential to assist in the struggle to raise incomes and alleviate poverty in the developing world. In its broadest sense, biotechnology encompasses a wide range of scientific approaches. These include various molecular techniques that can make conventional breeding more precise and allow for the transfer of useful traits across species, as well as cellular techniques such as tissue culture that can provide disease-free planting materials. Many developing countries are already adopting such technologies as plant tissue culture and micropropagation, diagnostics for crop and livestock diseases and the artificial insemination of livestock. By

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contrast, the potential of genetic engineering to confer a wide range of "pro-poor" traits, such as pest and disease resistance, tolerance to drought and salinity or improved nutrient content, has yet to be realized. Much greater technical capacity is needed to apply these techniques, which must be regulated since they pose possible risks to human health and the environment.

In addition, most research on modern biotechnology is being undertaken in the private sector of industrialized countries. Developments are occurring within a strict proprietary regime, where extensive patent laws protect both products and processes. As a result, the commercial application of agricultural biotechnology is highly concentrated by country (especially the US), by crop (especially soybeans and maize), and trait (especially herbicide tolerance and pest resistance) (Halweil, 1999). As a result, currently available transgenics – both traits and crops – have little relevance to poverty reduction in developing countries. To make agricultural biotechnology innovations relevant for developing countries, research needs to be aimed at staple foods for tropical and semi-tropical environments, labor-intensive technologies and traits desirable for small-farm systems that operate under extensive market and institutional failures (de Janvry et al., 1999; Nuffield Council on Bioethics, 1999).

For several reasons, the public sector will have to play a major role in developing crop varieties for many food crops, whether through conventional breeding or through biotechnology. First, as noted above, direct spillovers from private-sector biotechnology research in industrialized countries are likely to be minimal due to differences in crops and the problems of sub-tropical and tropical ecologies. But many of the molecular tools and processes that have been developed in industrialized countries are needed to advance the cause of biotechnology in developing countries. Second, small market size and the dominance of resource-poor farmers act as strong disincentives for private research and development (R&D) in many countries with emerging research systems. Third, even with the strengthening of intellectual property rights (IPRs) in developing countries, it will not be cost-effective to enforce them in small-farm situations. Except in some cases where hybrid-seed technology is available, it will be difficult for the private sector to recoup investments.[1]

Current public-sector capacities for agricultural biotechnology research in developing countries vary widely. Many larger countries in Asia, Latin

[1] Biologically-based technology protection systems that are under development for specific traits through genetic engineering might change this situation if seed viability is preserved and seed costs can be kept to reasonable levels for small producers. The same technology might also be used to induce male sterility and facilitate the development of hybrids in crops where hybrids are not now currently feasible.

America and Eastern Europe (e.g., Brazil, Mexico, China, India, Malaysia, Indonesia, Philippines, Thailand and Hungary) have a relatively high level of capacity for plant micropropagation, marker-assisted breeding, and, increasingly, in genetic engineering.[2] However, most smaller countries (especially Sub-Saharan African countries) lack the basic infrastructure and facilities for even plant tissue culture or micropropagation. Most of these small- and medium-sized developing countries are struggling to develop sustainable research programs against a background of a public funding crisis for research, fragile public research organizations and growing demands on science to address problems of rural poverty, food security and environmental conservation. Particularly for these countries, weak research systems, small market size and the predominance of resource-poor farmers will severely limit private-sector R&D investments for the foreseeable future (Maredia et al., 1999). In addition, we estimate that less than 10 percent of developing countries have established regulatory mechanisms to evaluate the risks and benefits of new biotechnologies, and only a few have the capacity to successfully negotiate access to proprietary tools and technologies from abroad. Although many countries are moving toward establishing these regulatory mechanisms – as required by international treaties – progress has been slow.

2 DEVELOPMENT ASSISTANCE AND AGRICULTURAL RESEARCH

Development assistance agencies (abbreviated in this paper to "donors") come in many shapes and colors and have often taken very different approaches to supporting agricultural research.[3] Donors are bilateral (e.g.,

[2] Observations of the frequency distribution of transgenic field trials across countries indicate that there are several developing countries with advanced research capacity in molecular techniques: notably China, Argentina, India, Brazil, Mexico and Egypt. Others have a more modest capacity, such as Indonesia, the Philippines and Kenya (Pray et al., 1999).

[3] Throughout this paper the term "donors" will be used for development assistance agencies, though it is recognized that development banks are in fact "lenders" and some other agencies may be collaborators rather than donors. Information on donor practices, strategies and policies was obtained from (i) a review of existing information, especially the work conducted by the Biotechnology Service (IBS) of the International Service for National Agricultural Research (ISNAR) in 1993, which was the first systematic effort to review international initiatives in agricultural biotechnology (Brenner and Komen, 1994) and led to the BioServe database at ISNAR, updated in 1996 and 1997, (ii) information provided directly by various donors through an informal survey that we conducted for the purpose of this paper, and (iii) donor publications and websites, including statements or position papers issued by various donors on agricultural biotechnology.

national development organizations), multilateral (e.g., World Bank, regional development banks, Food and Agriculture Organization of the United Nations (FAO)), or private not-for-profit organizations (e.g., the Rockefeller Foundation or church-sponsored non-governmental organizations (NGOs)). To some extent, private companies are also donors (Brenner and Komen, 1994). Donors generally provide either financial and technical support or both. Financial support may be through grants or loans on both concessional and commercial terms. Likewise, technical support may be provided through information sharing and other collaborative arrangements or through the provision of technical assistance. Most bilateral donors have more flexibility in choosing their partners in developing countries than multilateral agencies, which are bound to work with national governments.

Since the 1960s, development assistance agencies have played a major role in building national agricultural research systems (NARSs) in the developing world. Support for building agricultural research systems continues to be a priority for many development assistance agencies, including bilateral and multilateral donors, private agencies, and development banks. It is not surprising that these agencies have given such high priority to agricultural research. First, broad-based technical change in agriculture, especially in basic food crops, is now accepted as a necessary prerequisite for rapid increases in agricultural productivity and economic growth. Second, many studies of economic returns to investment in agricultural research in the developing world provide convincing evidence that this investment has paid high returns in many settings (e.g., Alston et al., 1998a). Third, the building of agricultural research capacity requires considerable investment in scientific skills, often through overseas postgraduate training, technical assistance in specialized fields of agricultural science, and investment in research infrastructure, all of which are skill and foreign-exchange intensive areas in which donors have a comparative advantage. Although early efforts to build national agricultural research systems were led by the Rockefeller and Ford Foundations (e.g., Mexico and India), other donors, especially the United States Agency for International Development (USAID) and the World Bank, soon enthusiastically responded to these challenges.

Donor support to research systems is provided in many forms: grants, concessional and non-concessional loans, technical assistance, and proceeds from food aid. Although no comprehensive figures are available, by the early 1980s, donors were investing over US $600 million per year in agricultural research in the developing world. This amounted to 2 percent of all aid and 6 percent of agricultural aid (Pardey et al., 1991). Since 1980, the World Bank has been the largest "donor," contributing over the past decade some US

$250-350 million annually to national agricultural research systems (Pritchard, 1994; Byerlee and Alex, 1997) and $50 million annually to the Consultative Group on International Agricultural Research (CGIAR). Historically, USAID has also been a large donor, providing $150-200 million annually to agricultural research in most years between 1980 and 1993, but since then its contribution has fallen to a very low level (Alex, 1997).

No data are available on overall trends in external aid to agricultural research, but using World Bank contributions as a guide, loans to agriculture tended to fall in absolute terms and as a share of total lending up to 1998, when this trend may have reversed. However, loans to agricultural research have increased or remained steady, so that the share of agricultural loans going to research has increased from 4 percent in 1981-84 to 8 percent in 1996-98.

A more useful way of viewing donor support to agricultural research is by estimating donor contributions in relation to the total amount invested in agricultural research in developing countries. In the 1980s, donors provided 16 percent of the total public investment in agricultural research in the developing world (Pardey et al., 1991). If we include donors' contributions to international agricultural research centers and networks, this amount increases to about 23 percent. The dependence on donor support, however, varied from virtually zero in a few countries to over 70 percent of the research budget in some countries. Using the same source, donor investment in agricultural research was highest in Africa (35 percent of total investments), followed by Asia (26%), West Asia and North Africa (11%), and Latin America (7%). In general, donor dependence is highest among smaller countries, many of which are struggling to develop their NARSs.

Since the early 1980s, by far the largest increase in donor funding for research has occurred in Sub-Saharan Africa. Using World Bank loans as a guide, Africa's share of total loans for agricultural research increased from 8 percent in 1977-84 to 44 percent in 1989-96, while the share to Southeast and East Asia and Latin America dropped sharply (Byerlee and Alex, 1997). Not surprisingly, the dependence on donors for agricultural research funding is currently highest in Sub-Saharan Africa, where the donor share grew from 34 percent to 43 percent over the short period, 1986-92 (Pardey et al., 1997). Including contributions to international agricultural research centers working in Africa, the total share of funds provided externally is over 60 percent.

With strong support from development assistance agencies, investment in agricultural research in developing countries grew at 6 percent annually from 1961 to 1985 (Alston et al., 1998b). Public-sector investment in agricultural research in developing countries now exceeds US $8 billion annually – equivalent to the public-sector investment in agricultural R&D in industrialized countries. In the past decade, however, there has been a sharp drop in domestic funding for research in many countries, especially in Latin America and Africa. Meanwhile, the size of research systems, measured by the number of scientists, continued to expand, resulting in reduced expenditures per scientist and a critical shortage of operating funds for research.

The emphasis of the major donors, such as the World Bank and USAID, in supporting research has also evolved. The emphasis can be broadly classified into three periods:

1. A period of expansion up to the early 1980s – the "bricks and mortars" phase – when the main emphasis was on creating and expanding the size of national public-sector research organizations (NAROs) through investment in experiment station and laboratory infrastructure, equipment, and human resources development.
2. A period of transition from the mid-1980s, when more emphasis was placed on improving the *management* of existing research resources in the NAROs through better planning, improved financial management, greater accountability, and more attention to increasing the relevance of the research program to its immediate clients: farmers. However, as in the first period, most resources in project loans for agricultural research were provided for further expansion and rehabilitation of research infrastructure.
3. The period from the mid 1990s, when donor projects began to emphasize measures to enhance the *institutional sustainability* of agricultural research systems. They shifted support away from the NARO towards building a more diverse NARS, which incorporates a range of institutional options for conducting agricultural R&D and a diversity of funding mechanisms that foster competition and improve articulation among the various participants in the expanded system (Echeverría et al., 1996).

The 1990s have also been characterized by the globalization of agricultural science, emphasizing regional and international collaboration and partnerships. This trend is partially in response to the growing complexity of agricultural research, both in terms of technical complexity (advances in molecular biology) and institutional complexity (the growing role of proprietary tools and technologies).

3 DEVELOPMENT ASSISTANCE AND BIOTECH

Support to biotechnology poses new challenges for external assistance agencies. In the first place, the earlier period of support to agricultural research systems was associated with links and technical assistance from the public sector of donor countries. But biotechnology research largely belongs to the private sector: it is generally assumed that roughly 80 percent of all investments in plant biotechnology R&D are made by private companies (Ozgediz, 1997). In developing countries, on the other hand, private-sector R&D typically accounts for only 10-15 percent of total agricultural R&D and only a fraction of this goes to biotechnology R&D (Pray and Umali-Deininger, 1998).

This concentration of private investments in biotechnology R&D and in industrialized-country agriculture is not likely to change in the near future, since commercial opportunities for investing in agri-biotechnology R&D in developing countries are limited. Only in markets that can be easily segmented by producer type is there a chance that private companies will make technology available to developing countries for free or for a nominal fee. This depends very much on the ability of countries or intermediaries, such as the International Service for the Acquisition of Agri-biotech Applications (ISAAA), to convince companies that it is in their interest to donate valuable biotechnology applications, so that appropriate regulations, seed distribution systems, and trust and confidence can be built as a pre-cursor for licensing arrangements and the building of various forms of alliances and joint ventures (Krattiger, 1998).

For these reasons, the public sector, both national and international, will remain in the years to come the principal source for biotechnology R&D investments in developing countries. In four countries where detailed data are available (Kenya, Mexico, Indonesia and Zimbabwe), public-sector organizations accounted for 92 percent of research expenditures on agricultural biotechnology from 1985-1997 (Falconi, 1999). Donors account for a considerable share of this investment – around 60 percent in the case of Kenya and Zimbabwe (Falconi, personal communication, 1999).[4] In addition, the research institutes of the CGIAR are spending somewhere between US $24 and 30 million per year on biotechnology research, roughly 15 percent of which goes to research on transgenics (Cohen et al., 1998). Over 95 percent of the support to the CGIAR is provided from the public

[4] Recent estimates, however, indicate that national governments in developing countries are gaining interest in agricultural biotechnology and, in the aggregate, might provide twice as much funding for biotechnology-related R&D in the public sector of developing countries as the international development community (Persley, personal communication, 1999).

funds of development assistance agencies of industrialized countries, although developing countries are increasing their contributions.

Even with strong donor support, resources for biotechnology research in developing countries will be small in relation to private R&D in industrialized countries. However, these funds are crucial to strengthen capacities, to develop partnerships, and to adapt technologies to the needs of developing countries, all of which will lay the foundation for greater private investment agri-biotechnology R&D in developing countries in the future.

3.1 The Potential Role of Donors

Donors operate under a set of development objectives or beliefs about how their overall goal can best be achieved. These development objectives are rooted in the national development policy of the donor's home country or countries and can be very different from each other. For example, some donors do not regard agricultural biotechnology as contributing to poverty alleviation in a significant way, while others do. And since they receive their funds from the general public, donors face a set of restrictions due to public opinion, which differs among countries (e.g., the debate on genetically modified organisms is much more heated in Europe than in the US, and European donors are more likely to face opposition when they fund projects that involve genetic engineering than American donors).

Donor objectives for external assistance have varied over the years. Recently, the central objective of most donors has been poverty alleviation. In the case of agricultural research, donors' main role in agricultural R&D is to support the generation of public good technologies that the private sector will not provide, but which will enhance food security and the incomes of poor producers and consumers. In the field of agricultural biotechnology, this can be done in various ways (see Figure 1):

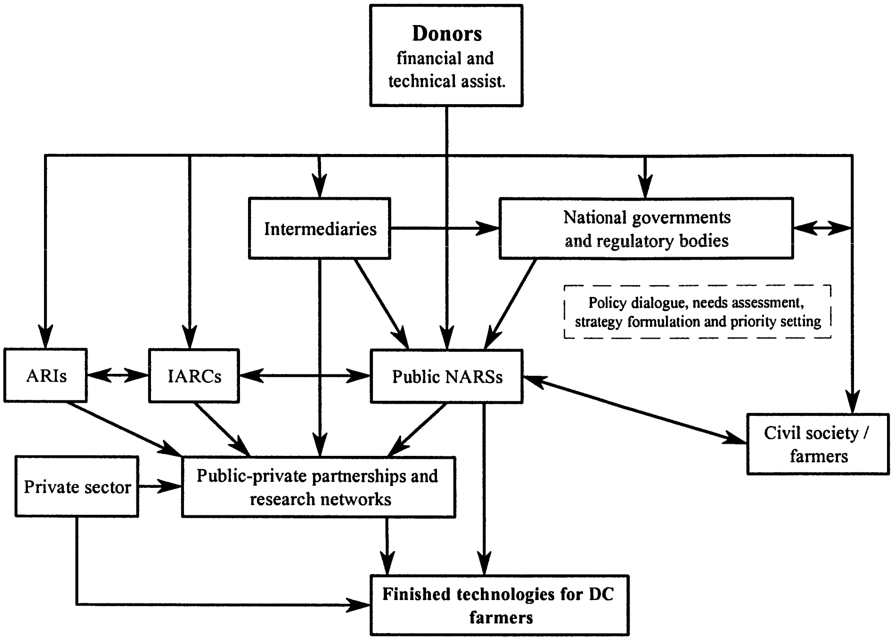
Providing advice and information for policy-making, through:

- direct provision of technical and policy advice and assistance; and
- support to intermediary organizations, such as IBS at ISNAR, ISAAA, and the Center for the Application of Molecular Biology to International Agriculture (CAMBIA), that provide advisory services to developing countries.

Investing to build public-sector research capacity through:

- development of human resources and hardware (buildings, equipment, etc.); and
- institutional development, especially the formulation of country priorities and strategies in biotechnology.

Figure 1: Pathways of donor support



Facilitating the access and transfer of technologies through:

- facilitating negotiation with private companies;
- strengthening the voice of developing countries in global policy dialogue; and
- supporting networking among research institutions in developing and in industrialized countries, among developing countries and at the regional level.

Funding research on a specific problem of wide interest to developing countries, including:

- research in the developing-country NARSs,
- research in the international agricultural research centers (IARCs) of the CGIAR; and
- research at advanced research institutes (ARIs) of industrialized countries.

Developing capacity in complementary areas, especially:

- support to design and implement an effective regulatory framework for biosafety, foodsafety, and IPRs; and

- facilitating capacity to exchange information and promote dialogue among stakeholders within and outside the country.

How donors choose among these alternatives depends on a variety of factors, including their own (national) development objectives and philosophy, the constraints imposed by public opinion in their home countries and historical legacy (e.g., former colonial ties). In the following section, we will look at some examples of what donors have chosen to do.

3.2 Current Donor Support to Agricultural Biotech R&D

In the 1980s, representatives of multilateral and bilateral donor organizations, and of national and international agricultural research institutes, met on several occasions to discuss the potential benefits and challenges agricultural biotechnology poses for developing countries (Komen, 1997). As a result of these meetings, which emphasized the need for special initiatives and new ways of doing business, donors developed a wide range of programs and activities, as well as a number of statements about how they were going to approach the issue of agricultural biotechnology.

Donor Policies and Strategies

At a time of heated debate and growing controversy about biotechnology, or more precisely about genetic engineering, a number of donors have developed statements that outline their policies and strategies with respect to biotechnology. The British Department for International Development (DFID), the German Ministry for Economic Cooperation and Development (BMZ) together with the German Technical Cooperation (GTZ), the Swiss Development Cooperation (SDC), the French Center for International Cooperation in Agricultural Research for Development (CIRAD), FAO, Rockefeller Foundation and the World Bank are among the donors that have statements in various stages of completion. USAID also has specific internal policies and procedures to ensure the safe development and application of biotechnology with respect to the environment and human health.[5] In their policy statements, donors stress:

- the generally positive potential of agricultural biotechnology to alleviate poverty;

[5] These cover the safe laboratory practices for recombinant DNA research, transfer of recombinant DNA applications from the US to developing countries, field testing, environmental assessments and human subjects concerns.

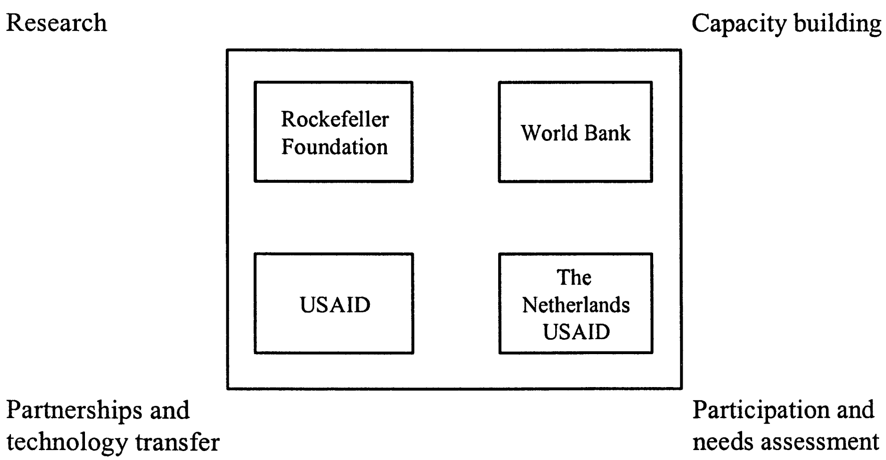
- the role of biotechnology as complementary rather than competitive to traditional technologies;
- the need for adequate biosafety provisions to be put in place;
- the need for a functional IPR framework in the receiving country,
- the need to build capacities for biotechnology R&D, policy analysis and technology application and acquisition in developing countries;
- the need to build partnerships of various kinds (e.g., regional cooperation among developing countries; North-South cooperation; public-private partnerships) not only for technology development, but also in the fields of biosafety, IPRs and genetic resources management;
- the need for ex ante cost-benefit assessments of investment in biotechnology and comprehensive risk-benefit assessments.

Based on these statements, the general impression is that donors have a fairly unified approach to supporting biotechnology for poverty alleviation. But, as shown below, these common principles often translate into very diverse actions.

Key Characteristics of Recent Donor Initiatives

For the sake of classification, we can distinguish four "typical" approaches that donors take to the issue of agricultural biotechnology. These approaches differ in that their main focus is either on funding research, on capacity building in the broad sense, on partnerships and technology transfer

Figure 2: Classification of approaches to support agri-biotechnology R&D



or on participatory approaches to priority setting and needs assessment (see Figure 2). Although reality is not quite as clear-cut as this classification suggests, four of the major donors for biotechnology R&D illustrate these approaches.

Focus on Research – The Rockefeller Foundation

The Rockefeller Foundation is the most important donor among private foundations in the field of agricultural biotechnology. Its main activity since 1984 has been the International Rice Biotechnology Program (IRBP), which has two objectives: to develop knowledge and tools for rice that can be used to produce improved rice varieties suited to the needs of developing countries, and to ensure that scientists in developing countries know how to use and adapt such techniques for their own priorities (Herdt, 1995). IRBP involves an international network of researchers in universities and public research institutions in both industrialized and developing countries, as well as at international institutions such as the International Rice Research Institute (IRRI), the International Center for Genetic Engineering and Biotechnology (ICGEB), the West Africa Rice Development Association (WARDA), and the International Center for Tropical Agriculture (CIAT). Over the 16 years of its existence (1984-1999), it has been funded with a total of over US $100 million. Initially, the major share of grant funding went to "first world" laboratories in order to build a rice biotechnology knowledge base, but by 1994 there were 76 developing country research institutions participating in the program, mainly in Asia.

In 1988, researchers in the network transformed rice, a first for any cereal (Herdt, 1995). A recent success story is the development of a new rice variety that contains beta-carotene ("golden rice") and makes iron more readily available for human digestion. However, although transformed rice has been field-tested and a number of lines now exist with agronomically useful traits, commercial products have yet to be released. Country approval has been slow due to insufficient biosafety provisions and public opposition. IPR-related problems have also slowed commercialization. Recently, the Rockefeller Foundation has been shifting its emphasis away from rice to a more geographic focus on Africa and to stress resistance in all crops. Given the experience with rice, it has also identified IPRs and biosafety as new areas of concentration. Although the volume of funding will generally increase in the next couple of years (from a low of US $6.5 million in 1996-99 to a high of $9.2 million in 2001-03), there will be rather drastic cuts in some areas, such as education and the IARCs. In line with its new emphasis on IPRs, the Rockefeller Foundation supports CAMBIA's Intellectual Property Resource for International Agricultural Biotechnology (CIPR) (see Box 1).

Box 1: The Rockefeller Foundation and CAMBIA's Intellectual Property Resource for International Agricultural Biotechnology (CIPR)

The CAMBIA intellectual property (IP) strategy group is a facility that intends to increase the capacity of the international agricultural research community to address IP issues relevant to biotechnology in a strategic and proactive manner. Clients for this resource activity will include both public-sector participants, such as national programs of the developing world, CGIAR–supported centers, NGOs and policy-makers dealing with IPRs in the developing world and private-sector participants, such as national seed companies of the developing world.

A key component of the activities of CAMBIA's IP Facility is to greatly strengthen the in-house capabilities of national programs, small breeding companies and international institutions. In this regard, the Facility will use a variety of procedures, protocols, databases and educational materials and activities. This will allow the clients to incorporate IP-based strategies and knowledge in the development and deployment of their research activities, to foster fair and equitable license arrangements and to increase the likelihood of achieving successful commercialization of research results in resource-poor farming communities.

CAMBIA envisions that the most wide-reaching resource within the Facility will be the patent database. With the database, a user will be able to readily access published patents and patent applications from many jurisdictions, such as the US, Europe and Japan. An associated database will include nucleotide and amino acid sequences that are disclosed in the patents and patent applications.

Additional components of the database resource will provide possible interpretations of the claims of key patents and white papers analyzing patent positions for aspects of agricultural biotechnology (e.g., transformation, vectors, promoters, and plant genes encoding traits). The resource will be available by internet access.

Funding for CIPR is provided by The Rockefeller Foundation.

Source: CAMBIA's website: www.cambia.org/main/ip_stratgr.htm

Focus on Capacity Building – The World Bank

The World Bank is the largest source of external assistance for agricultural research. As such, it provides significant resources for capacity building in NARSs in general. However, it provides few resources for biotechnology. It is estimated that of the total outstanding loan portfolio of US $2 billion for agricultural research, less than $50 million (2.5%) is earmarked for biotechnology support. Most of this support is for "lower end" biotechnology, especially tissue culture and diagnostics, and this is confined to a few medium and larger countries (see Table 1). In two countries, India

Table 1: Support for biotechnology [a] in World Bank projects

Country	Year began	Project title	Total cost (mill. US$)	Biotech cost (mill. US$)	Type of support for biotech
Turkey	1992	Agriculture Research	77	n.a.	Commodity research
India	1993	Agr. Development Project-Rajasthan	130	1.0	Policy support; capacity building
Indonesia	1995	Agr. Research Management	102	2.6	Policy support; capacity building
Bangladesh	1996	Agr. Research Management	59	0.6	Capacity building
Kenya	1997	Nat. Agr. Research Project II	180	n.a.	Policy & regul. reform; commod. research
Brazil	1997	Agr. Technology Development	120	18.0	Policy & regul. reform; commod. research
Ethiopia	1998	Agr. Research and Training Project	91	3.8	Cap. building; commodity res.
Brazil	1998	Science and Technology	n.a.	4.2	Capacity building
India	1998	Nat. Agr. Technology Project	240	15.0	Cap. building.; commod. res.; priority setting
Total			2,000 [b]	About 50	

Note: n.a. means not available.

a. Broadly defined (see next section) to include tissue culture, diagnostics, and DNA technologies, but not artificial insemination.

b. All research projects, including those that do not support biotechnology.

Source: Internal World Bank estimates.

and Brazil, World Bank loans support molecular biology research, including genetic engineering work in India. The World Bank also provides $50 million annually to the CGIAR. Loan funds support a variety of capacity-building activities, including laboratories and infrastructure, human resources development, technical assistance, national and regional networks and international collaboration with ARIs in the public and private sectors of industrialized countries. Recently, more emphasis is being placed on building capacity in appropriate regulatory frameworks for biosafety and IPR and on supporting the development of national strategies and priorities (e.g., Ethiopia and Kenya).

Currently, a taskforce has been established within the Bank's Vice Presidency for Environmentally and Socially Sustainable Development, and an international workshop was held in June 1999. An options paper under preparation proposes that Bank actions focus on:

- developing capacity in client countries to make informed decisions (enhancing technical ability to evaluate technologies, analyze options, formulate strategies, develop effective regulatory and biosafety protocols, and mechanisms for monitoring and assessment);
- identifying and supporting efforts in biotechnology that maximize the potential to alleviate rural poverty;
- promoting technological alternatives, especially through building support for a strong agricultural research system that provides research products and processes that are international public goods (internationally through the CGIAR, and nationally by encouraging investments in national agricultural research systems);
- providing a platform for reasoned debate on issues of biotechnology, based on scientific evidence, and directed toward the common good.

Focus on Public-Private Partnerships and Technology Transfer – USAID

USAID's main initiative in plant biotechnology is the Agricultural Biotechnology Support Project (ABSP), implemented by a consortium of public- and private-sector institutions in the US and abroad, with Michigan State University as the lead entity (Ives et al., 1998). This project started in 1992 with a six-year budget of US $6.7 million. The project takes a product-oriented, collaborative approach that integrates research, product development, human resource development, biosafety and IPR issues. ABSP conducts collaborative research on the development and testing of genetically engineered pest-resistant crops and on the tissue culture of tropical crops. It is targeted at a limited number of crops, chosen either for their importance in food security (sweetpotato, potato, maize, banana) or for their potential as a source of economic development (potato, cucurbits, banana, pineapple and tomato) (Ives et al., 1998).

Another, smaller USAID project in cooperation with ISAAA involves the transfer of proprietary technology from an international private company, Monsanto, to the Kenya Agricultural Research Institute (KARI). Monsanto's transformation technologies have been used to develop a variety of genetically engineered sweetpotato with resistance to feathery mottle virus (Komen, 1997). In addition, USAID supports two initiatives in the livestock biotechnology sector: a Rinderpest Vaccine project (implemented through the University of California at Davis along with the Pan African Rinderpest Campaign) and a Heartwater Vaccine project (implemented through the University of Florida in collaboration with the Veterinary Service of

Zimbabwe). USAID's total estimated annual expenditures for agricultural biotechnology (plants and livestock) amount to US $8 million.

Focus on Participatory Approaches and Needs Assessment – The Netherlands Development Cooperation

In 1992, the Directorate-General for International Cooperation of the Ministry of Foreign Affairs of The Netherlands launched its Special Program for Biotechnology and Development Cooperation (DGIS/BIOTECH). This program has allocated a total of US $27 million for the period 1992-97. The program is specifically directed towards small-scale producers, especially women, in developing countries. It focuses on a limited number of countries (Kenya, Zimbabwe, Colombia and India) and is to a large extent decentralized. Local steering committees, which include representatives from farmers' organizations and individual farmers, are taking responsibility for project implementation and management. Emphasis is given to the identification of farmers' needs through a participatory, "bottom-up" approach. The process of needs assessments and priority setting has been completed in each focal country, and the following projects have been initiated (Komen, 1997):

- marker-assisted selection of drought-tolerant and insect-resistant maize (Zimbabwe and Kenya, in collaboration with the International Center for Maize and Wheat Improvement (CIMMYT));
- micropropagation of disease-free planting material (all countries); and
- production of biofertilizers and biopesticides (Kenya, India).

In addition, the program has an international component through support to IBS at ISNAR and the Cassava Biotechnology Network (CBN) at CIAT (see Box 2).

Other Donors

The mentioned organizations are only four of a large number of donors engaged in agricultural biotechnology. Most donors (including the four donors used as case studies here) will typically engage in a combination of activities. Table 2 provides an overview of the activities of a larger group of donors, based on information that was readily available. For the sake of classification, we have attempted to assign a catchphrase to each donor that attempts to capture in a simplistic manner the overall philosophy and priorities of each donor. Table 3 summarizes this information according to the pattern of intervention, following the classification provided in Figure 1.

Box 2: The Cassava Biotechnology Network (CBN)

Founded in 1988, CBN originated as an initiative of CIAT, the International Institute of Tropical Agriculture (IITA), and individual scientists from advanced laboratories. Funding for a CBN Coordination Office was provided in 1992 by DGIS/BIOTECH. CBN's objectives are (i) to integrate farmers' priorities into the research agenda for cassava biotechnology, (ii) to foster demand-led cassava biotechnology research, and (iii) to promote information and technology exchange among farmers, advanced laboratories and national programs.

As the Network looked ahead to a future technology transfer stage, it became clear that if biotechnology was to help provide better food security, CBN must do more than foster the cost-effective development of a powerful new tool kit. It would also be essential to help create the conditions necessary for generating and successfully moving specific, appropriate technologies from concept to adoption (Thro, 1998).

In setting its priorities, and also to plan arrangements for technology transfer, CBN is working closely with intermediate experts in national cassava R&D programs. At the same time, DGIS/BIOTECH challenged CBN Coordination to bring cassava's end-users, especially small-holder farmers and rural processors, into the decision-making process for research. DGIS/BIOTECH also helped provide opportunities to explore priorities and experimental solutions interactively with cassava's end users.

By 1997, CBN had about 400 members working on the development or application of cassava biotechnology tools and a similar number of members in a national program in developing countries who conduct applied cassava R&D. About 60 percent of the "biotechnology" membership is located in 26 cassava-growing developing countries, about 30 percent in 13 economically advanced countries, and about 10 percent in CGIAR Centers. They conduct research in three types of cassava biotechnology: (i) approximately 40 percent in genetic biotechnologies (molecular genetics and genetic transformation), (ii) approximately 30 percent in tissue culture, and (iii) approximately 30 percent in fermentation biotechnologies.

CBN has emerged at the end of its first phase with a two-fold strategic lesson: (i) achieving CBN's goal in the long run, will require close links with cassava's end users (the small-holder farmers and rural processors who depend on cassava) and (ii) developing effective farmer links requires significant investments in time and attention (Thro, 1998).

By adding up the numbers in Table 2, we estimate that donors provide somewhere between US $40 million and $50 million per year for agricultural biotechnology. Including the roughly $30 million spent by the CGIAR, we estimate that the international donor community invests between US $70-80 million in agricultural biotechnology R&D annually.[6] Even though many donors claim to have no specific regional focus, this investment is concentrated in just a few countries. Small countries are generally not involved. Some medium-sized countries are developing programs with donor assistance, and some large countries have programs that receive substantial national support but are still complemented with external assistance (e.g., India and Brazil).

Table 2: Main external assistance activities of donors in agricultural biotechnology

Donor	Main activities	Regional focus	Annual budget
The Rockefeller Foundation – Increasing productivity through biotech research	International Rice Biotechnology Network; shifting emphasis to Africa, general stress tolerance; support to CIPR (see Box 1); support to ISAAA and the CGIAR	Previously Asia; now: Africa	Betw. $6-9 million/year (plant biotech only)
World Bank – Capacity building for informed decision making	Agricultural research projects in some countries have a biotech component to support capacity building (e.g., India, Brazil, Ethiopia, Kenya, Bangladesh, see Table 1); support to the CGIAR	International	Around $10 million/year for biotech broadly defined
FAO – Maintaining a balanced perspective	Acts within the framework of existing nat. research agendas and priorities through consultations, monitoring, and program initiatives; concentrates on activities such as providing information, monitoring and advice, facilitating access to the new technologies, providing a forum for the review of trends, dev. appropriate guidelines and codes to facilitate the environmentally sound harnessing of modern biotech, assisting dev. countries to identify biotech needs and priorities and to assess socioeconomic impacts, and strengthening the overall biotech capabilities of the dev. countries (FAO, 1995)	International	No information available

[6] There might be some double-counting because donor support to agricultural biotechnology is likely to include their support to the CGIAR. However, this effect is neutralized by the fact that information from a number of donors was not available (e.g., Japan, Germany, Switzerland, Sweden) and thus was not included in the calculation.

Table 2 (continued)

Donor	Main activities	Regional focus	Annual budget
BMZ/GTZ (Germany) – Getting technologies to the farmers	Various activities in the field of biosafety and IPRs (studies, workshops, symposiums, trainings); field studies and training programs for economic analyses of biotech; various activities in tissue culture, mass propagation, genetic resources conservation, molecular markers, diagnostic kits for a broad range of crops (fruit trees, coconut, leguminous feed crops, potatoes, cassava, horticultural crops), livestock (cattle) in a number of countries; support to ISAAA, the CGIAR, the Asian Vegetable Research and Development Center, Cerrados Agricultural Research Center/Brazil	International	No information available
USAID (United States) – Fostering public-private partnerships	ABSP (Michigan State University); Rinderpest Vaccine (University of California (Davis) and Pan African Rinderpest Campaign); Heartwater Vaccine (University of Florida and Veterinary Service of Zimbabwe); support to the CGIAR	Indonesia Egypt Kenya Zimbabwe	Around $8 million/year for agricultural biotech (plants and livestock)
DFID (United Kingdom) – Biosafety first	Plant Science Research Programme (PSRP), University of Wales – advanced plant breeding and crop physiology projects at various British public and private institutions and IARCs; Biotechnology Programme, managed by the Natural Resources Research Department at ODA (now DFID); funds are distributed over some 12 research projects, mostly at British public institutions (Komen, 1997); support to the CGIAR	International	Latest estimate: $4.1 million/year (Komen, 1997)
France – Cash crop research for development	Support to CIRAD, which works in some 50 countries, on a wide variety of crops (banana/plantain, citrus, cocoa, coconut, coffee, cotton, oilpalm, rice, rubber tree, sorghum, sugarcane, forestry species), utilizing a wide variety of techniques (mass propagation, molecular markers, genome mapping, genetic transformation); support to the CGIAR	International	Latest estimate: $7.5 million/year (Komen, 1997)

Table 2 (continued)

Donor	Main activities	Regional focus	Annual budget
IDRC (Canada) – Promoting business ventures with Latin America	CamBioTec: promoting biotech through Canada-Latin America Partnerships; brokers connections with laboratories, firms, and research organizations; arranges executive seminars and partnering meetings and serves as a guide to local market and technical information; support to the Crucible Group I and II; support to the CGIAR	Latin America	No information available
Swedish Intern. Dev. Coop. Agency (SIDA) and Swedish Assistance for Research Coop. with DCs (SAREC)	BioEARN, East Africa; support to the CGIAR; support to the Crucible II Process; support to studies on plant genetic resources	East Africa	No information available
Swiss Dev. Cooperation – Getting the policies right	Indo-Swiss collaboration in biotech; support to IBS, ISAAA and the CGIAR; support to policy work on plant genetic resources (e.g., the Crucible II Process); cassava biotech research at the Center for International Agriculture, Federal Institute of Technology Zurich (ETHZ)	India	No information available
The Netherlands Dev. Coop. – Bottom-up participation and needs assessment	Biotech Country Programs in India, Zimbabwe, Kenya, and Colombia; CBN (see Box 2); Biotechnology and Development Monitor; support to IBS; support to the CGIAR	India Zimbabwe Kenya Colombia	Approx. $4.5 million/year (Komen, 1997)

Source: See footnote 3.

No estimates are available on investments by NARSs in biotechnology, but given available data, they may be investing US $100-150 million annually from their own resources. The total investment of over $200 million from donors and developing country NARSs is significant but still small in relation to the estimated more than US $1 billion invested by private companies in industrialized countries.

Table 3 shows that most categories and sub-categories of support are covered by at least one donor, but that donors vary widely in their emphasis. This tells us two things: on the one hand, all of these categories seem relevant from the point of view of donors. On the other hand, donors have

Table 3: Donor support for R&D by pattern of intervention, with special emphasis on biotechnology

	Technol-ogy transfer	Building public-sector research capacity	Funding of direct research through			Promot-ing publ.-priv. partner-ships	Strength-ening regula-tory frame-works	Needs assess-ment and stakehol-der dia-logue	Technical and pol-icy ad-vice and assistance	Support to inter-mediary organiza-tions	Support to global policy dialogue
			CGIAR	NARSs	ARIs						
Rockefeller Foundation			X	XX	XX					X	
World Bank		XX	X	X		X	planned		X		
FAO		X	X					X	XX		XX
Australia			X	X	X	X					
IDRC	x	x	X			X	X				XX
DFID			X	X	X						
France		X	X	X	X	X					
SDC	X	X	X	X	X				XX	X	X
SIDA/SAREC		X	X	X	X	X		X		X	X
The Netherlands			X			X	X	XX			
USAID	XX	X	X	X	X	XX	XX		X		

Source: See footnote 3.

extremely varied approaches to using agricultural biotechnology to alleviate poverty. Given the limited funds available, this is a worrying observation. Not only is there a missed opportunity for exploiting economies of size, but there is also the danger that recipient countries, in their attempts to obtain support from different donors, will be confused and prevented from developing a clear strategy. One promising way out of this dilemma is the emergence of multi-donor initiatives.

Multi-Donor Initiatives

Currently, at least five initiatives are supported by more than one donor. These initiatives function as intermediaries through which donors can combine their efforts to provide biotechnology access for the poor.

CGIAR. The largest of these initiatives is the CGIAR, which is essentially supported by all donors. Since there is another paper on this topic in this book, we will not discuss the role of the CGIAR here. Suffice it to say that the CGIAR is a center (or rather, several centers) of excellence in the field of plant breeding and livestock biotechnology. Its mission is to alleviate poverty by providing international public goods. If we are to bring the potential of biotechnology to resource-poor farmers and foster the sustainable use of natural resources, the CGIAR must be supported by all donors. Currently, the CGIAR invests roughly US $30 million annually in biotechnology-related research that is directed toward the needs of small-scale farmers in developing countries. These investments are small and fragmented, often according to specific donor projects.

IBS. Situated within the CGIAR system is the second initiative that receives funds from several donors, namely ISNAR's IBS. The governments of the Netherlands, Switzerland and Japan mainly support IBS. For specific past and current activities, additional support is provided by DFID, SIDA, the Technical Centre for Agricultural and Rural Cooperation (CTA), and the Development Center of the Organization for Economic Cooperation and Development (OECD) (ISNAR website: www.cgiar.org/isnar). IBS is an independent advisor to developing countries on matters of biotechnology policy and management and on socioeconomic and technical issues. A work program has been formulated that covers two broad areas: (i) research (on topics such as research indicators on agricultural biotechnology, impact analysis and priority setting for biotechnology research), and (ii) outreach (e.g., policy and management courses, in-country advisory service, and regional policy seminars).

ISAAA. The third initiative that is a combined effort of several donors is ISAAA. Again, we will not go into any detail since ISAAA is well represented in other papers of this book (but see www.isaaa.org for further information). It is funded by a donor support group consisting of public- and private-sector institutions. Funds are made available for institutional support (13 donors), specific projects (11 donors), or for the ISAAA Biotechnology Fellowship Program (13 donors). But overall support is small, with an estimated annual budget of roughly US $2.5 million including projects in Africa, Southeast Asia and Mexico.

CAMBIA. The fourth initiative is CAMBIA, an independent, nonprofit research institute located at the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia. CAMBIA focuses its research on techniques that will benefit developing country farmers – for example, apomixis, a trait that promises the benefits of hybrid seed without the expense involved in purchasing new seed for each crop cycle. CAMBIA provides training and technology transfer services (including advice on IPR matters, see Box 1). CAMBIA is financed by philanthropic organizations, by national and international research funding bodies, by royalties derived from licensing its own technologies and by limited commercial R&D partnerships.

ICGEB. Finally, in the 1980s the international donor community decided to set up a specialized international institute for biotechnology within the UN system, ICGEB, with research facilities in Trieste and New Delhi. From their website (www.icgeb.trieste.it) and annual report, it appears that they are engaged in more basic research. They are also involved in the breeding of *Bacillus thuringiensis* (*Bt*) rice, in collaboration with affiliated centers (currently 32, not more than one per member state).

3.3 Assessment of Donors' Effectiveness

From the above review, several general impressions and conclusions emerge. First, it is clear that individual donor contributions to biotechnology are small in relation to the challenges facing developing countries, and also in relation to private-sector investment in R&D in industrialized countries. Indeed, developing countries' needs are likely to be even greater if biotechnology is to address complex multi-gene traits, such as stress tolerances, that are important for resource-poor farmers. In addition, research support is now a declining share of total development assistance for most donors, and within this support, very few emphasize investment in biotechnology capacity. The controversy about transgenics has undoubtedly reduced the support of some key European donors that have historically been strong supporters of agricultural research, such as DFID (UK). Even for a large donor, such as the World Bank, investment in biotechnology research capacity has so far been small, with the major emphasis of its lending program focused on downstream activities. The Rockefeller Foundation, an NGO, is the only major donor that has focused a large share of its development assistance on biotechnology research over many years.

Second, the impacts of the investments have so far been limited. Although there are good examples of the wide adoption of tissue culture techniques, with high economic payoffs (e.g., Qaim, 1999), investments in transgenics have yet to show results on the ground. The only transgenics under commercial production in developing countries, outside of China, have been developed through the efforts of private R&D. Several transgenic products have been developed through donor support, such as virus-resistant potatoes and sweetpotatoes, and rice varieties for virus, disease and insect resistance, but these are only now reaching the field-testing stage. For example, after over 15 years and over US $100 million investment, transgenic rice varieties have yet to be field-tested in Asia (with the possible exception of China), due to problems in obtaining biosafety permits and public resistance in some countries. Furthermore, proprietary rights associated with several genes and processes incorporated into these varieties have yet to be negotiated for commercial use.

Third, investments to date have emphasized technology development at the expense of investment in national regulatory systems, research capacity building and public dialogue. Under-investment in these areas has become apparent as technologies reach the stage of field-testing, and as the rapid spread of transgenics in some industrialized countries has heightened the debate about environmental, health and ethical risks. In many cases, technologies that are available cannot be imported due to a lack of IPR systems, or cannot be field-tested due to a lack of biosafety regulations or public opposition. In several developing countries, there is a strong anti-biotechnology sentiment among various farmer, environmental and consumer groups, but little external assistance has been offered to facilitate public dialogue about the potential and risks of the new technologies.

Fourth, donor support has tended to be fragmented, except when several donors jointly support multi-donor efforts, such as ISAAA and the CGIAR. Even in these cases, support tends to be "projectized" with individual donors often financing special projects. There is currently no clear international consensus on priorities for investment in biotechnology to guide a coordinated multi-lateral effort. More importantly, there is no clear consensus on whether investment in biotechnology is a priority relative to other forms of R&D investments. The CGIAR, which is a key player in providing developing countries – especially smaller ones – access to the new technologies, has no central focus to its biotechnology work and only recently allocated a significant budget to biotechnology.

Finally, external assistance, with a few notable exceptions, such as USAID and ISAAA, has tended to focus on public-sector investments, paying little attention to utilizing the large capacity of the private sector, or to accessing currently available private-sector tools and technologies to achieve wider social benefits. Because of the public-good nature of most biotechnologies for resource-poor farmers, public funding of research is essential. However, much of the needed research could be executed in the private sector, as long as IPRs are held by the funding agency. Innovative public-private partnerships need to be discussed, such as the establishment of a fund to contract private R&D firms to develop high priority technologies of global significance in the developing world, with payment conditional on product delivery (Sachs, 1999).

4 CONCLUSION

We conclude that donor support is urgently needed to mobilize the potential of agricultural biotechnology to benefit the poor. Long-term and concerted donor support is essential for providing developing countries access to biotechnology and allowing them to adapt it to their specific needs. The development of regulatory frameworks needed for the acquisition and safe application of technologies from abroad and of NARS capacities in biotechnology R&D, will be much slower without donor support in these times of extremely tight government budgets. Although the amount of external assistance funding (perhaps US $75 million/year) for biotechnology is small compared to the over $1 billion spent by private companies in industrialized countries, these funds constitute a considerable proportion of total investment in agricultural biotechnology R&D in developing countries, especially outside of the three "NARS giants" (India, China and Brazil).

The biotechnology challenge is occurring at a time of declining donor support for agricultural research and of tight funding for NARSs that is jeopardizing even the survival of conventional breeding programs. Greatly enhanced donor and national government research budgets must work on (i) crops and traits that are important for the urban and rural poor but that are not being addressed by private-sector research and (ii) a more complete understanding of the ecosystems into which these new technologies will be introduced (de Janvry et al., 1999). At the same time, the benefits of this investment will only be realized if complementary investments are made in traditional areas of agricultural science, especially plant breeding. Support to biotechnology should not be at the expense of traditional research, but should take the form of a concerted effort to sharply raise the total investment in agricultural research at the national and international levels, so that scientific advances can be harnessed to solve food security and poverty problems.

We also conclude that a more concerted effort by donors is needed to enhance the effectiveness of current investments. There is a need to pool available resources through collaborative arrangements (e.g., partnerships, consortia, contract research) to identify and address high priority problems on a global scale for developing-country farmers. Such collaboration would bring together corporate, non-profit, public and international institutions (especially the CGIAR) to develop biotechnology products and related services favorable to poverty reduction. An integrated strategy would also ensure that technology development, regulatory frameworks and public dialogue are all addressed simultaneously.

Such an approach would give special attention to relationships with the private sector that could provide better access to proprietary tools and products. In practice, markets for applying these tools and products can often be effectively segmented, encouraging private markets where they are feasible and underwriting costs of providing products in "non-market" situations. A coordinated approach by the international donor community could assemble a critical mass of money, skills and political weight to facilitate negotiation with the private sector. Innovative mechanisms are needed, such as a global research fund, that pools donor contributions to contract private-sector expertise on a competitive basis to address high priority problems of relevance to the developing world.

Considerable dialogue is needed with clients and other stakeholders to establish priorities for biotechnology investment versus other types of research, as well as priorities within biotechnology that will maximize benefits for the poor. The lesson of the recent past is that without up front dialogue, progress in biotechnology deployment in the developing world will be much slower – and may even be reversed. Using experience gained from their host countries, donors are in a unique position to foster such dialogue as part of their development assistance programs for agricultural research.

DISCLAIMER

Gesa Horstkotte-Wesseler and Derek Byerlee are with the Technical Centre for Agricultural and Rural Cooperation (CTA) and the World Bank, respectively. Opinions expressed in this paper are those of the authors.

REFERENCES

Alex, G. (1997): USAID and Agricultural Research. ESDAR Special Report, No. 3, World Bank, Washington, D.C.

Alston, J.M., M.C. Marra, P.G. Pardey, and T.J Wyatt (1998a): Research Returns Redux: A Meta-Analysis of the Returns to Agricultural R&D. EPTD Discussion Paper, No. 38. International Food Policy Research Institute, Washington, D.C.

Alston, J.M., P.G. Pardey, and J. Roseboom (1998b): Financing Agricultural Research: International Investment Patterns and Policy Perspectives. *World Development* 26 (6), pp. 1057-1071.

Brenner, C., and J. Komen (1994): International Initiatives in Biotechnology for Developing Country Agriculture: Promises and Problems. OECD Development Centre Technical Papers, No. 100, Organization for Economic Cooperation and Development, Paris.

Byerlee, D., and G. Alex (1997): Strategic Issues for Agricultural Research Policy to 2000 and Beyond. Technical Paper, World Bank, Washington, D.C.

Cohen, J., C. Falconi, J. Komen, and M. Blakeney (1998): Proprietary Biotechnology Inputs and International Agricultural Research. ISNAR Briefing Paper, No. 39, International Service for National Agricultural Research, The Hague.

de Janvry, A., G. Graff, E. Sadoulet, and D. Zilberman (1999): Technological Change in Agriculture and Poverty Reduction. Unpublished concept paper for the World Development Report on Poverty and Development 2000/01.

Echeverría, R.G., E.J. Trigo, and D. Byerlee (1996): Institutional Change and Effective Financing of Agricultural Research in Latin America. Inter-American Development Bank and World Bank, Washington, D.C.

Falconi, C.A. (1999): Agricultural Biotechnology Research Indicators in Developing Countries. Paper prepared for the conference "The Shape of the Coming Agricultural Biotechnology Transformation", 17-19 June, Tor Vergata University, Rome.

FAO (1995): Agricultural Biotechnology in the Developing World. FAO Research and Technology Paper 6, Food and Agriculture Organization of the United Nations, Rome.

Halweil, B. (1999): The Emperor's New Crops. *World Watch* (July/August), pp. 21-29.

Herdt, R.W. (1995): The Potential Role of Biotechnology in Solving Food Production and Environmental Problems in Developing Countries. In: A.S.R. Juo, and R.D. Freed (eds.). *Agriculture and Environment: Bridging Food Production and Environmental Protection in Developing Countries*. American Society of Agronomy, Cincinnati, pp. 33-54.

Ives, C.L., B.M. Bedford, and K.M. Maredia. (1998): The Agricultural Biotechnology for Sustainable Productivity Project: A New Model in Collaborative Development. In: C.L. Ives, and B.M. Bedford (eds.). *Agricultural Biotechnology in International Development*. CAB International, Wallingford, UK, pp. 1-14.

Komen, J. (1997): International Initiatives in Agri-food Biotechnology. Chapter prepared for the volume "Biotechnology Worldwide" (forthcoming).

Krattiger, A.F. (1998): The Importance of Ag-biotech to Global Prosperity. ISAAA Briefs, No. 6, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

Maredia, M., D. Byerlee, and K. Maredia (1999): Investment Strategies for Biotechnology in Emerging Research Systems. Paper prepared for the conference "The Shape of the Coming Agricultural Biotechnology Transformation", 17-19 June, Tor Vergata University, Rome.

Nuffield Council on Bioethics (1999): Genetically Modified Crops – The Ethical and Social Issues. Nuffield Foundation, London.

Ozgediz, S. (1997): Strengthening CGIAR-Private Sector Partnerships in Biotechnology: A Private Sector Committee Perspective in Compelling Issues. Paper prepared for the mid-term meeting 1997, Consultative Group on International Agricultural Research, Cairo.

Pardey, P.G., J. Roseboom, and J.R. Anderson. (1991): Topical Perspectives on National Agricultural Research. In: Pardey, P.G., J. Roseboom, and J.R. Anderson (eds.). *Agricultural Research Policy: International Quantitative Perspectives*. Cambridge University Press, Cambridge, pp. 265-308.

Pardey, P.G., J. Roseboom, and N.M. Beintema (1997): Investments in African Agricultural Research. *World Development* 25 (3), pp. 409-423.

Persley, G.J. and J.J. Doyle (1999): Brief 1: Overview. In: G.J. Persley (ed.). Biotechnology for Developing-Country Agriculture: Problems and Opportunities. International Food Policy Research Institute, Washington, D.C.

Pray, C., A. Courtmanche, and M. Brennan (1999): The Importance of Policies and Regulations in the International Spread of Plant Biotechnology Research. Paper prepared for the conference "The Shape of the Coming Agricultural Biotechnology Transformation", 17-19 June, Tor Vergata University, Rome.

Pray, C., and D. Umali-Deininger (1998): The Private Sector in Agricultural Research Systems: Will it Fill the Gap? *World Development* 26 (6), pp. 1127-1148.

Pritchard, A.J. (1994): World Bank Investment in Agricultural Research Policy and Strategy: Past and Future. In: J.R. Anderson (ed.). *Agricultural Technology: Policy Issues for the International Community*. CAB International, Wallingford, UK, pp. 45-58.

Qaim, M. (1999): Assessing the Impact of Banana Biotechnology in Kenya. ISAAA Briefs, No. 10, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

Sachs, J. (1999): Helping the World's Poorest. *The Economist*, 14 August, pp. 17-20.

Thro, A. (1998): Cassava Biotechnology Research: Beyond the Toolbox. In: C.L. Ives and B.M. Bedford (eds.). *Agricultural Biotechnology in International Development*. CAB International, Wallingford, UK. pp. 229-245.

Chapter 23

CONCLUSIONS [#]

Anatole F. Krattiger, Matin Qaim, and Joachim von Braun

1 INTRODUCTION

The individual chapters in this book tackled the potentials and constraints of agricultural biotechnology in developing countries from various perspectives. Without trying to reiterate all the important statements, this conclusions chapter synthesizes the major findings and discusses related institutional, policy and research implications.

The lives of the poor are marked by low per capita incomes, deficiencies in basic needs, lack of rights, insufficient infrastructure, production that is focused on domestic requirements or subsistence, low agricultural productivity and generally weak foreign trade relationships. Population growth further aggravates this situation. Forty thousand children die every day because of malnutrition and deficient health systems: fifteen million children each year. Eight-hundred million people suffer from chronic undernutrition. There is an international responsibility, an ethical imperative, to act. But what actions should be taken? Certainly there are no easy or isolated solutions to these complex problems of hunger and poverty. Concerted actions are required, but, apart from economic, social and political instruments, technological measures have to be an integral part of any long-term poverty reduction strategy.

Agriculture is the engine of growth in developing countries' economies, for it is still the sector that provides employment and income for most of the

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[#] The text of this conclusions chapter partly draws on a panel discussion held at the end of the conference on which this book is based. The discussion was moderated by Anatole F. Krattiger, and the panelists included Robert W. Herdt, Clive James, Emil Q. Javier, Suri Sehgal, Eduardo J. Trigo, Florence Wambugu, Brian D. Wright and Usha Barwale Zehr. While individual statements made may not be fully represented, their contributions are gratefully acknowledged.

M. Qaim et al. (eds.),
Agricultural Biotechnology in Developing Countries: Towards Optimizing the Benefits for the Poor, 409–423.

population. Indeed, unless small-scale farmers' incomes are enhanced, their exodus to cities (too often to the city slums) will continue, further impoverishing both rural and urban areas. Added value in agriculture and the rural economy could slow that trend. And investments in agricultural research and development (R&D) are good ways to improve the economic wellbeing of many low-income countries and their citizens' food security and purchasing power, and thus their health, education and prosperity. However, in some parts of the world it has become increasingly difficult to maintain past agricultural growth rates based on available technologies. Other areas have never seen modern production technologies due to agroecological or institutional constraints. Crop biotechnology has the capacity to improve this situation.

Biotechnology should not be understood as a substitute for traditional tools of crop improvement, but integrating biotechnological techniques into conventional breeding programs could substantially enhance the efficiency of agricultural R&D. On the one hand, breeding could be accelerated through a more targeted transfer of desired genes into crops. On the other hand, biotechnology could bring forth new crop traits that are not amenable to a conventional approach. Agronomic or input traits, such as genetic resistance mechanisms against biotic and abiotic stress factors, could boost crop output in all agroecological areas, even in those marginal lands that have not been reached by the green revolution. Moreover, genetic resistances against pests and diseases could increasingly substitute for chemical plant protection measures, thus contributing to a reduction of adverse environmental effects. Quality or output traits, including enhanced micronutrient contents in staple foods, could improve the nutritional and health situation of millions of consumers who are too poor to afford sufficient amounts of more expensive and nutritious foodstuffs. Some technologies have already been commercialized. Others, such as the production of pharmaceuticals and specialty chemicals in the plant, are already in the research pipeline. But today's technologies are only the beginning; there is tremendous potential to be realized over the next few decades, particularly through the exploitation of functional genomics. Predicting what tomorrow's technologies will bring us is essentially impossible with such diverse opportunities.

These potentials suggest that transferring biotechnology to developing countries holds great promise for agricultural producers and consumers alike. Many suggest that tissue culture is the most appropriate technology for developing countries and that these countries should not get involved with more complex transgenic technologies. Certainly tissue culture has great potential, as some of the papers in this book clearly demonstrate. But a close and careful look also shows how appropriate transgenic crops might be for smallholder, semi-subsistence agriculture. Although the development of transgenic varieties is a sophisticated process at the R&D level, the final output can easily be integrated into traditional farming systems. After all, once acquired, the technology can easily be reproduced by the farmers themselves and does not generally require new applications of fertilizers, irrigation or other inputs that green-revolution technologies require – everything is "packaged" in the seed.

In spite of the great potentials, however, we see only few concrete applications of modern biotechnology in developing-country agriculture. Although a number of interesting project examples have been presented, we cannot be blind to the fact that biotechnology developments are so far mostly concentrated on large-scale, commercial agriculture in industrialized and some middle-income countries. Around 80 percent of all research investments in agricultural biotechnology are made by the private sector, which is focusing its efforts on key global crops and traits rather than on orphan markets in low-income countries. Thus, end-technologies as well as important research tools are becoming increasingly proprietary, with a massive concentration of relevant intellectual property rights (IPRs) in the corporate sector. At the same time, international development investments in agriculture by the public sector are dwindling. The biotechnology revolution will bypass the poor, unless suitable policy mechanisms are developed and implemented to improve developing countries' access to the required innovations. The remainder of this last chapter addresses the following two questions, which are central to the whole design of the book:

- What are the main economic and institutional constraints that might hinder an equitable biotechnology evolution, and what needs to be done to overcome these constraints?
- In what particular areas can more policy-oriented research improve the knowledge base for related decisions?

2 ECONOMIC AND INSTITUTIONAL CONSTRAINTS

2.1 Private-Sector Constraints

One of the areas this book has highlighted is the private sector's current and potential role in disseminating agricultural biotechnology to developing countries. However, even if effective transfer mechanisms are established, can the types of agricultural biotechnologies developed by the private sector meet the needs of the poor? The first wave of agricultural biotechnology – insect and virus resistance, herbicide tolerance and improved post-harvest handling characteristics – has been commercialized in such crops as soybeans, maize, cotton, canola, papaya and several vegetables. Increasing productivity and reducing the need for pesticides, these traits are most useful for large-scale farming, and, although they could also benefit subsistence farmers, such crops and traits have primarily been adapted for developed countries.

Why is the private sector concentrating on these few crops and traits? Primarily because of the enormous investments required to develop a genetically modified variety. Companies are currently investing several billion dollars into biotechnology R&D annually. These huge investments require significant marketing potentials, and so the private sector has focused on crops with large acreages and thus high cash value. Consequently, the agronomic knowledge and experience of both the private seed sector and the crop chemical sector is almost exclusively limited to these commercially important crops. In fact, companies have little knowledge about other crops and their importance to the world's poor. This is not surprising since little or no returns on private-sector investments can be generated in these "non-commercial" markets.

The problem of high investment requirements is compounded by the problem of time. Biosafety and foodsafety regulations are prolonging the time needed to develop transgenic crops. It is estimated that the time from discovery to market is moving from six to more than ten years – in some cases even longer. Likewise, the cost to develop a transgenic variety has escalated by millions of dollars, largely because of higher regulatory requirements. With added layers of regulation, such as those brought about by the Biosafety Protocol under the Convention on Biological Diversity, costs might increase even more in the future. The long development periods also limit the time a company can take advantage of its patents. Because it has only a limited amount of time to obtain a return on its investments, a company will focus on crops with large, predictable and well-established markets. Although – if adapted to local needs – most if not all commercialized biotechnology applications could be of relevance to poor population segments, the private sector alone cannot provide the desirable end-technologies for non-commercial markets.

2.2 Public-Sector Constraints

Research domains neglected by the private sector have traditionally been filled by public national agricultural research systems (NARSs) and the centers of the Consultative Group on International Agricultural Research (CGIAR). But many public organizations were rather slow to recognize the big potentials of biotechnology for the developing world and their related capacities are immature in many instances. Moreover, the overall resources made available for agricultural research are dwindling, which also hampers the effectiveness of public biotechnology programs. Currently, the global public investments in agricultural biotechnology with relevance to developing countries are estimated at a level of US $200 million per year. This is much less than the annual research budget of one single multinational biotechnology company. Although the meaning of such a comparison is certainly limited, it has to be stated that the present public investments are insufficient to secure an adequate flow of advantageous biotechnology products to the poor.

However, in addition to financial constraints there are also institutional shortcomings limiting the effectiveness of public biotechnology R&D. Isolated niches for public research cannot easily be defined anymore, because basic biotechnology tools often apply to a diverse range of crops and problems. Given the concentration of patents in the corporate sector it would be difficult or impossible for public research to access even elementary tools without interacting with private companies. This is a new challenge for public organizations, one that requires institutional adjustments and, in part, a re-definition of their traditional mandates. Creating innovative partnerships between the public and private sectors based on comparative advantages is the only way to ensure that technologies emerge that can address the specific problems of the poor.

But even when appropriate end-technologies are being developed, the innovation has to be implemented in agricultural practice. This presupposes effective regulatory mechanisms for responsible risk management (i.e., biosafety) as well as sound technology delivery systems at the national and local level. Although transgenic crop varieties in particular could be integrated into smallholder farming systems more easily than most conventional technologies, preliminary case-study experience shows that both market and policy failures might restrict technology access for the poor. Accordingly, innovative partnerships between the relevant players have to be developed to disseminate available technologies equitably.

3 POLICY IMPLICATIONS

In order to capitalize on the biotechnology potentials for food security and poverty reduction, a significant expansion of public financial commitments is indispensable. However, whether or not biotechnology's promise will reach resource-poor farmers and consumers in developing countries will also to a great extent depend on whether or not we can develop the necessary institutions. An efficient institutional infrastructure requires pragmatic collaborations in international R&D as well as suitable frameworks for IPRs, biosafety, technology transfer and local capacity building. Although much more socioeconomic research is needed before conclusive statements about appropriate institutional designs can be made, this section discusses related challenges for national and international policies. Bringing about institutional change is always a big challenge, but we can identify some ideas and broad outlines that address how current institutions can adapt and capitalize on biotechnology today so that they can be more effective tomorrow.

3.1 Public-Private Partnerships

Given the constraints described above, it is obvious that the private sector alone cannot provide the end-technologies needed by poor agricultural producers and consumers in developing countries. Therefore, the public sector must explicitly address those promising technology areas where private efforts cannot be expected, such as tolerance mechanisms in crops against diverse abiotic stresses (e.g., drought, nutrient deficiencies), which are particularly important for rainfed, marginal lands. But also for micronutrient-dense staple foods, which could primarily benefit poor food consumers, the commercial incentives for private research are most probably too small. Public institutes, including the CGIAR centers, advanced research institutes (ARIs) in the North and leading institutes in the developing world, should focus on developing such orphan traits.

Nonetheless, most technologies developed by the private sector could also be useful for non-commercial markets if adapted to specific crops and needs. This holds true for resistance genes, which can often be used for a diverse range of crop species, and for the wide array of enabling technologies. Evidently, there is an opportunity to capitalize on the efforts that have already been made by investing a little bit more to adapt and transfer these proprietary technologies to developing countries. In this regard, strong collaborations between the private sector and national and international public research institutes appear to be the only way forward. Indeed, considering global resource scarcities and the lead that private companies have in biotechnology R&D, there is a responsibility to make use of the private sector's tools and talent to make them contribute to a common human goal.

We must remember, however, that although biotechnology can do many things, we may end up wasting a lot of resources and time if we fail to think through the consequences of our efforts. Therefore, we must move ahead by dealing with specific crops and projects on a case-by-case basis. Blindly building public-private partnerships is not sufficient. The experience with such partnerships to-date should be considered to identify weaknesses and build on strengths. Alliances should not primarily be led by short-term goals, such as generating income through licensing agreements or exploiting the value of one's assets. This could jeopardize the quality of research and thus the long-term success of an organization. Furthermore, partnerships should be flexible and not only geared towards one-to-one relationships. Agreements that are too tight might restrict an organization's "freedom to operate" and distract public institutes from their actual objectives.

One major problem with public-private collaborations generally is that the public sector does not have a sense of the specific issues at stake in making a partnership. The level of knowledge and sophistication is quite a bit higher than most public-sector organizations realize. There are two types of difficulties: institutional and operational. On the institutional side, the challenge is to bring two organizations together with very different cultures. The private sector is driven by profit; the public sector by service. There are also motivations and incentives on the private side to develop a product on time that are often lacking in national programs. When one tries to integrate these institutions, one has to expect problems. But we should not be put off by some initial difficulties. We can consider forging public-private partnerships as similar to the production of a hybrid, where synergistic effects are exploited through the crossing of two inbred lines. The papers in this book clearly show that building trust and confidence is essential – nothing gets done otherwise.

On the operational side, there are a couple of issues. One is the availability of technology. IPRs are also obviously a big challenge, and there are no easy answers (also see next sub-section). And finally, one major constraint is that the public sector often cannot define the problem, which makes it difficult to come up with a solution. What is needed is a clear identification of priorities. This requires multidisciplinary research, explicitly taking into account the voices of the poor themselves. Clearly defined priorities would also make it easier for donor organizations to fund collaborative research, coordinate their efforts and thus enhance the effectiveness of current investments.

3.2 IPR Issues

Biotechnology will affect our lives in ways that we cannot foresee. Twenty-five years ago, very few people – if anyone – could have guessed what we see the future holds. These exciting possibilities in biotechnology have been made possible largely because the private sector has invested billions of dollars in research. Companies recognized an opportunity, they had a vision and they took high risks. It seems important – and logical – not to be pushing for the demand that all the research already done should revert "back to the commons", that the private investments and patents should be given to the public sector. If what we see today is only the very beginning of a new technology revolution in the life sciences, then the last thing we want to do is undermine the investment incentives for sustained innovation.

Overcoming the Ideology-Driven Debate

The question whether patents are good or bad is quite irrelevant for our purposes, since the answer to such a question can only be found in different ideologies. Ideology, however, is one of the major constraints in implementing institutional measures that could enable the poor to benefit from biotechnology. It is time to put aside ideological differences about IPRs and talk about them in economic terms. If a country does not provide a certain level of protection for innovation, investments in new technologies are discouraged. Yet it has certainly become much too expensive for most public-sector players to participate in patenting because of the tremendous cost and complexity. Also, excessive patenting increases the transaction costs in research (e.g., search costs, protracted negotiations with different parties, enforcing rights through contracts or within lawsuits) which might stifle follow-on research and the speed of innovation, besides fostering further market concentration in the future.

The relevant question, therefore, is what the appropriate level of protection might be. Too little protection discourages investments, whereas too much protection also reduces society's gains. Finding a balance is the critical issue. The level of protection must be seen in at least two dimensions. First, the time period for which protection is granted. Traditional patent durations of 18 to 20 years might be too long for the area of biotechnology, where innovation currently takes place at very fast rates. Yet increasingly complex regulatory processes in biotechnology delay the time to market so that too short protection periods might also constitute a hindrance for commercial innovation. Second, there is the scope of patents, or the question of what a protectable invention is. Very broad patents can be problematic. Patenting entire plant genomes or genetic sequences without knowledge about their function, for instance, may constrain future innovation rather than enhance it.

We do not know yet how our institutions will deal with IPRs or whether they will be able to take advantage of them. We do know, however, that IPRs are here to stay (in one way or another) and that they will certainly shape the way our institutions develop (cf. Santaniello et al., 2000). While more economic research is needed before we can identify appropriate international IPR frameworks and accompanying institutions (e.g., antitrust laws, clearing house mechanisms), we must not delay in pursuing the opportunities that exist today for practical cooperation and outreach to the poor. Accessing IPR-relevant information appears to be an important drawback for many developing countries. Therefore, the options of establishing regional patent offices with a strong legal services function (e.g., designed after the model of the European Patent Office) should be carefully considered.

IPRs in Research Collaborations and Technology Transfer

It has been pointed out repeatedly that public-private partnerships have to be strengthened in order to make promising biotechnologies available to the poor. One option already practiced to some extent is that CGIAR centers or NARS institutes use private-sector technologies and apply them to the problems of their client countries. A key question, however, is the ownership of the final technologies developed by public organizations, technologies that are developed partly through proprietary inputs. In the past, this was not always clarified before large public R&D investments were made. Insufficient agreements, however, can lead to frustration and a waste of resources since private companies may eventually block the release of emerging technology products. Working with proprietary technology components requires careful contractual arrangements for each specific case, stating where, under what conditions and for what purpose the technology might or might not be used by the license-taker. If such contractual arrangements cannot be ensured, private companies are understandably hesitant to license patented innovations to public institutes. Bilateral agreements between a company and a single developing country are much easier to negotiate than multilateral ones.

Because of their global mandate and public good policy, for instance, the CGIAR centers find it difficult to get access to proprietary research tools and technologies for further adjustment and final release. Given the international exchange of germplasm, it could not be ruled out that the resulting public-sector technologies with proprietary components would also be used in countries where the conditions for commercial technology releases by the patent-holding firms are favorable. Yet adopting a more aggressive attitude towards IPRs would meet a lot of resistance because it would so fundamentally change the system, the basis of which has been the free availability of all its products. What is clear is that the CGIAR cannot expect to generate significant revenues from participating in patenting. Instead, the system will seek to ensure that technologies will continue to be available to the widest possible number of users. Nevertheless, a strong argument in favor of patenting is that it could generate bargaining chips that would allow the CGIAR centers to obtain through cross-licensing other critical technologies needed in the development of their products for the poor. It must not be forgotten, though, that patenting is associated with tremendous administrative costs, which might easily overstrain the CGIAR's capacity and would divert human and financial resources from its research programs. The design of appropriate IPR policies to facilitate broader collaborations with the private sector remains an important issue for the CGIAR centers and other public institutes.

One option is to segment commercial and non-commercial markets. If private companies can watch over their safe employment, there is no reason why they should not agree to license proprietary technologies to public institutes for use in non-commercial markets, while selling the technology themselves in commercial markets. Market segmentation appears feasible in a geographical sense, for instance, between rich and poor countries, and different crop species could be segmented as well. Biotechnology can provide the means for the transfer of genetic material across species, so that certain genes used by private firms in commercial crops could also be valuable for public R&D on orphan commodities.

While the lack of public acceptance is often considered an obstacle to biotechnology development, it also has its positive aspects. It is partly due to the strong influence of internationally active non-governmental organizations (NGOs) that the public image of private companies – especially large, multinational corporations – becomes increasingly important for long-term business success. For reasons of public relations it is therefore attractive for the private sector to become engaged in philanthropic projects meant to benefit the poor in developing countries. This has been demonstrated by several private-public technology donations that have been presented and analyzed in previous chapters. But even if technologies are donated by the private sector, they need to be adapted to locally grown varieties and crops. This has its cost too: adapting an on-the-shelf technology for crops needed by poor farmers requires about eight to ten years and substantial investments (cf. Qaim, 2000). CGIAR centers, NARSs and donor organizations must develop strategies to capitalize on industry's new attitude and to make technology donations most effective.

Alternative Incentives for Private R&D

Owing to the experience they have already acquired in biotechnology R&D, private companies often have a comparative advantage over public institutes in developing certain technologies. But private companies will only invest when they can make money out of their inventions. Granting IPRs is one way to encourage private-sector R&D. However, due to the complications that arise from increased patenting, this leaves the problems of the poor unsolved. They cannot translate their needs into effective economic demand to pay for research results. An alternative method of tapping the private sector's skills for the benefit of the poor is to promise a market for certain research outputs. Jeffrey Sachs (1999) proposes a possible avenue for developing medicines, such as malaria vaccines. He suggests that the public sector make available a certain amount of funds to any private (or public) research institution that could deliver a desired vaccine that meets certain minimum requirements of efficacy. This would help to set incentives for the private sector to become engaged in a research direction that would otherwise be unattractive, and it would also foster competition among various research actors. Public funds would only need to be spent upon successful product delivery. Could such a mechanism work for agricultural biotechnologies? If the public sector is truly concerned about securing certain technologies for poor producers and consumers, there is no reason not to define the objective, put up the money and let those who develop that technology have access to the funds.

Whenever a government, or any other body, can define a specific technological goal, the price mechanism has a potentially stronger attraction than patents. But this goal must be clear and simple. One thing that is of great concern is that we often expect technologies to meet too many criteria – and all of them simultaneously. This is undoubtedly the case with biotechnology, as it was, for example, with the green revolution. The latter successfully met the tremendous increases in food demand, yet many people today still believe that the green revolution was unsuccessful because it did not fulfill the many wonderful additional goals that were tacked onto it. If the benefits of biotechnology are to be shared with the poor, then simple and achievable goals have to be defined and prioritized. This would also help to redirect the biotechnology revolution from its present supply-driven course to a more demand-driven one.

3.3 Strengthening NARSs

Regardless of who develops a certain basic biotechnology, before it can be used in developing-country agriculture, it has to be adjusted to national conditions, tested locally and distributed to farmers' fields. Thus, the role of the national innovation system is central to any biotechnology strategy, and this must be recognized in international programs. In order to strengthen the national system, relevant biotechnology R&D should always be carried out in close cooperation with NARS scientists, and the technology should be transferred as a package of R&D capacities rather than just in the form of an end-product. International biotechnology transfer should be orchestrated on a case-by-case basis as "bundled endeavors", in which the technology product itself is only one of many elements. In the long run, such an approach will also reduce developing countries' technological dependence on the North and lay the basis for the development of commercial markets.

Overall, a decentralization process is required to effectively build R&D capacity. In this respect, the international donor community is challenged to make it easier for scientists in developing countries to access funding for research. This could be done by selecting one crop production problem of importance to poor people and training local scientists to address that problem through collaborative research. Training local scientists in such research is a problem-oriented approach involving both biotechnology and conventional agriculture. It builds capacity that will then be available to address other problems in the future. Besides providing funding for research, donors should implement overall strategies to strengthen institutions and regulatory frameworks in developing-country NARSs, including the ability to implement the Biosafety Protocol. Again, hands-on training within international collaborative projects is probably the best strategy. North-South technology and knowledge transfers are crucial for local capacity building. Yet greater emphasis should also be placed on South-South transfers and regional cooperation, which requires, *inter alia*, a better coordination of donor support and a shift from bilateral to multilateral projects.

Finally, it must not be forgotten that strengthening biotechnology R&D capacity is not sufficient if technology delivery systems are unsustainable. The widespread failure of much-needed technologies to reach the poor is due to a large extent to the limitations and partial failures of public governments. Traditionally, technology dissemination in smallholder agriculture has been considered a public-sector task because it was believed that the private sector would automatically be biased against the poor. But in fact the private sector is not the problem – it can be part of the solution. We should broaden our view of the agricultural technology delivery systems. Innovative partnerships should be considered between public organizations, the national and multinational private sectors, NGOs and farmers. Existing formal and informal networks and institutions should be harnessed to reap the largest benefits of new technologies for the poor.

4 RESEARCH IMPLICATIONS

4.1 Requirements for Policy Analysis

The international biotechnology evolution is still in its early stages, and so several related institutional and policy issues cannot all be tackled conclusively at this point. We must adopt appropriate policies to ensure that the technology evolution takes desirable directions. Far-reaching technologies such as biotechnology can both contribute and thwart development objectives. Policy analysts should learn from the past and provide timely information that helps to maximize technology advantages while minimizing negative impacts. More research is needed on two particular fronts.

First, there must be a systematic quantification of biotechnology benefits. This is also important for the public debate, which often overemphasizes technology risks. Preliminary work on evaluating ex ante the socioeconomic implications of biotechnology products has been presented. Such research is an important tool to facilitate decision-making processes at national and international levels, and we suggest that further studies be carried out in the future. For example, more methodological work is required to assess the positive effects associated with modified output traits, where the benefits cannot simply be expressed in terms of yield advantages. Also, it is important to note that agricultural technologies usually entail multiplier effects far beyond the agricultural and food sector, with positive repercussions for the overall economy (e.g., Hazell and Ramasamy, 1991). The employment of general equilibrium models could, therefore, be useful to give a picture of important intersectoral spillovers brought about by technological progress in agriculture. Finally, now that modern biotechnology has entered the stage of application in several developing countries, evaluations should steadily also include ex post approaches. Ex post studies could help support ex ante statements and provide better insights into such aspects as technology adoption patterns, distributional outcomes, environmental and health effects and others.

Second, there must be comprehensive scrutiny of IPR implications. The ramifications of strengthened IPRs for the biotechnology evolution are not yet well understood. It is important to overcome related ideological statements through economic research. Methodological tools have to be developed to study the impacts of strengthened IPRs on the structure of markets for intermediate and final technology products. The impacts on the speed of innovation development, public and private sector R&D roles and developing countries' access to biotechnology – with a special consideration of the small farm sector – should also be examined. Patents and other IPRs are instruments to maximize social welfare. But technological innovation calls for institutional innovation. While pragmatic and quick solutions are required in the short run, we must also search for options of broader institutional change in the long run. With respect to IPRs, the establishment of international bodies, such as regional or worldwide patent registration systems, clearing-house mechanisms and antitrust authorities, must be taken into account. Researchers should actively participate in this discussion and support policy-makers through sound analyses.

4.2 Communicating Research Results

Producing research results with respect to the implications of biotechnology is important, but it is not sufficient to maximize the technology's benefits. Research results have to be communicated to the public and to policy-makers. Weak public acceptance of biotechnology is largely due to half-truths and deliberate propaganda from antagonistic interest groups. Researchers have an important role to play in (re)gaining credibility and in rationalizing what has become an emotional debate. True, there are certain health, environmental and social risks associated with biotechnology, and the precautionary principle foreseen in the Biosafety Protocol might be justified to some extent. But safety measures should be based on science rather than opinion.

It must also be stressed that responsible technology management cannot be confined to the risk side only; it must include benefits as well. While in industrialized countries the benefits of today's biotechnology products accrue primarily to companies and commercial farmers (food price reductions are of minor importance for rich consumers), in developing countries the poor population segments could become the main beneficiaries on both the production and consumption sides. As for biosafety aspects, a credible monitoring system for the actual and potential benefits of biotechnology, with a regular meeting schedule, should be established for comprehensive technology assessment. Without sound knowledge on the benefit side, especially the benefits in developing countries, we are not in a position to assess the "risks" associated with not using biotechnology due to innovation blockades and delays. Appropriate technology communication is a social science research theme that hitherto has not been adequately covered.

Educating policy-makers so that they can make better decisions means more than simply sharing information. Case studies are of critical importance for a thorough analysis of the unique problems of developing countries and the benefits and constraints of biotechnology in these situations. Since far-reaching decisions often have to be made before a country begins to use modern biotechnology, bringing policy-makers from developing to developed countries to establish contacts and get information first hand is important. This should extend to working with newspaper editors and the media in general, because any policy-maker has to rely heavily on what the press states. If the media is misinformed and has misconceptions, then rational and objective policy decisions can hardly be expected. Also, it is important to develop more school- and university-type educational activities for the public, explicitly tackling widely held prejudices.

Overall, sharing information and knowledge requires different types of skills, different types of networks and the ability to communicate at many different levels. Trust and confidence are the foundation of partnerships, and without open and honest communication systems noone will win. This is why science-based information is so critical and why more research into the implications of agricultural biotechnology is needed to optimize the benefits for the poor.

REFERENCES

Hazell, P.B.R., and C. Ramasamy (1991): *The Green Revolution Reconsidered; The Impact of High-Yielding Rice Varieties in South India*. The Johns Hopkins University Press, Baltimore.

Qaim, M. (2000): *Potential Impacts of Crop Biotechnology in Developing Countries*. Peter Lang Publishers, Frankfurt.

Sachs, J. (1999): Helping the World's Poorest. *The Economist*, 14 August, pp. 17-20.

Santaniello, V., R.E. Evenson, D. Zilberman, and G.A. Carlson (eds.) (2000): *Agriculture and Intellectual Property Rights: Economic, Institutional and Implementation Issues in Biotechnology*. CAB International, Wallingford, UK.

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