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RESEARCH AT A GLANCE

Biotechnology and Genetic Resource Policies

Edited by Philip G. Pardey and Bonwoo Koo

January 2003

Briefs 1–6

THE INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE (IFPRI)

IFPRI was established in 1975 to identify and analyze national and international strategies and policies for meeting the food needs of the developing world on a sustainable basis, with particular emphasis on low-income countries and poor people; to make the results of its research available to all those in a position to use them; and to help strengthen institutions conducting research and applying research results in developing countries.

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ABOUT RESEARCH AT A GLANCE AND THIS SERIES

Researchers and policy analysts increasingly need concise, comprehensive information on all aspects of complex research issues. IFPRI's Research at a Glance series has been designed to meet this need.This volume contains the first of a series of IFPRI briefs on biotechnology and genetic resource policies. The briefs present syntheses and synopses of research conducted by a team from IFPRI's Environment and Production Technology Division and several collaborators. The team focuses on issues related to intellectual property rights, genetic resource management and conservation, biodiversity, and biotechnology.

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Cover photo credits

The collage background represents a Diversity Array Technology (DArT) image, a form of "DNA on a chip" technology developed by CAMBIA for low-cost genome analysis, here being used on rice. The image was generated by Damian Jaccoud. He is a student working under the supervision of CAMBIA's chief scientist, Andrzej Kilian.

RESEARCH AT A GLANCE

Biotechnology and Genetic Resource Policies

Brief 1, January 2003

Policy, National Regulation, and International Standards for GM Foods

Peter W. B. Phillips

The introduction of biotechnology into the agri-food world in the 1990s complicated an already difficult regulatory and trade system. At one level, biotechnology and genetically modified (GM) foods increase the potential for trade and the need for a fully functioning international trading system. At another level, the products of this new technology have precipitated a large and difficult debate about the structure and effectiveness of national food safety regulations and the appropriate role for international institutions. A number of national and international efforts are underway to manage these pressures, but prospects for early resolution are not great.

Biotechnology, Production, and Agri-food Trade

Biotechnology is inextricably linked to international trade. The technology has been globally developed and is being applied to research programs in more than 30 countries around the world. Biotechnology has had the greatest effect on the most heavily traded agri-food commodities in the global trading system.

Although the first biotechnology-based agri-food product entered the market only in 1994, by 2001 more than 50 modifications involving 13 crops had been approved and produced on more than 52 million hectares in at least 14 countries. Commercial production of GM foods has been concentrated in canola, corn, cotton, and soybeans, which are extensively traded internationally. Perhaps most important, GM production has been concentrated in countries that are the traditional and dominant exporters of those crops (particularly Argentina, Canada, China, and the United States). Up to 88 percent of trade in some of the products with GM varieties comes from the key GM-adopting countries (Table 1). For the most part, GM products have been marketed as commodi-

Table 1—Production and trade of GM agri-food products, 2000

Crop	Number of producing countries	Percent of global exports from GM producers	Number of importing countries
Maize/corn	8	85	168
Soybeans	6	88	114
Canola	2	50	68

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ties and mixed with batches of GM and non-GM products as they flow into the international marketplace and then to many countries around the globe. Once in these markets, the commodities are extensively processed, and their components (edible oils, corn meals, soybean proteins, and so on) are fundamental ingredients in more than 70 percent of the processed foods available in most developed-country markets.

GM products appear to simply raise new concerns about access to international markets. Those few countries producing and exporting the products seek to be able to continue their business unimpeded. Yet GM varieties tend to exacerbate the debate about market access because almost all the biotechnology traits in commercial production—herbicide tolerance, insect resistance, and viral resistance—lower production costs or increase yields. Those countries adopting these technologies, which also tend to be traditional exporters, thereby increase their exportable surpluses, depressing world prices and making nonadopting importing producers less competitive. As a result, disadvantaged farmers may join with consumers in importing countries concerned about the safety of these products in calling for increased controls on these products.

The Domestic Regulatory Response

A number of factors have made this issue hard to handle. Uncertainty about the food and environmental safety of new GM foods has led to different responses in different markets. Those markets lacking domestic regulators that command the confidence of consumers have tended to act in a "precautionary" way, either reviewing the products more slowly or imposing temporary bans on the introduction of the new products. This is a sharp break from the international food safety system that evolved over the past 100 years, where importers tended to accept the food and environmental safety judgments of regulators from those countries developing and exporting the products. One result of this "renationalization" of agri-food safety regulation is that national systems have tended to diverge. Canada, Japan, Mexico, and the United States, among others, generally make similar rulings and have approved most of the new GM products for production and consumption. Regulators in Australia, the European Union (EU), and New Zealand, in contrast, have postponed approvals in recent years, reflecting the concerns of their citizens. Another 20 or so countries have developed domestic regulatory systems consistent with one or other of these approaches.

The diverging domestic systems are most evident when one looks at the labeling systems being proposed or developed in various countries (Phillips and McNeill 2001). So far more than 26 countries have either adopted provisions or announced plans for rules to help the market develop and deliver labeled products. At one extreme, Argentina, Canada, Hong Kong, and the United States have adopted a voluntary labeling strategy that will likely allow labels for either GM or GM-free products, with only 1–5 percent tolerances for comingling. At the other extreme, 22 countries and the EU have adopted or announced plans to implement mandatory labeling systems. As of June 2002, only a handful of these countries had revealed the full structure of the labeling rules they intend to pursue, and only Australia, China, Japan, New Zealand, South Korea, and the United Kingdom have formally implemented labeling systems. A number of other countries have proposed mandatory labeling (for example, Brazil, Czech Republic, Hungary, Indonesia, Poland, Russia, South Africa, and Thailand), but there is little available evidence that these countries have developed domestic systems to manage such regulations or, for that matter, any firm indication of when their systems might be operational.

The key concern about the diverging domestic regulatory systems is that production and trade are shifting. Key GM adopters, especially Canada and the United States, are abandoning or losing key markets and diverting their exports to new markets. U.S. exports of corn to the EU have fallen by 70 percent in recent years, U.S. exports of soybeans to the EU have dropped by 48 percent, and Canadian exports of canola to the EU have dropped 96 percent. Meanwhile, the EU has developed new GM-free sources of soybeans from Brazil and canola from Australia, both markets that have not yet approved GM varieties for those crops. So far these changing trade flows have not significantly affected producer returns—trade has simply been reallocated between adopting and nonadopting countries—but over time such policies have the potential to seriously distort trade flows and offset many of the benefits of recently negotiated international trade agreements for these products.

Most of the rest of the countries in the world do not have any domestic regulatory capacity and are seeking guidance and help from international institutions.

The International Regulatory Response

Nine international bodies are currently vying to coordinate and regulate different aspects of food safety (Table 2). These institutions fall into three types. Five are largely science-based organizations: the International Plant Protection Convention (IPPC), International Epizootics Organization (OIE), Codex Alimentarius (Codex), the Food and Agriculture Organization of the United Nations (FAO), and the World Health Organization (WHO). One, the World Trade Organization (WTO), is a trade-based organization. The three others have broader objectives such as environmental protection and other social or political goals: the Organisation of Economic Co-operation and Development (OECD), Regional Initiatives, and the Cartagena BioSafety Protocol (BSP). These organizations seek to develop standards for health, safety, and labeling for GM foods, establish testing procedures to ensure the standards are met, provide rules for allowable policies, and create systems to manage disputes (see Buckingham and Phillips 2001).

Despite the substantial effort being undertaken, there is no common view on the goal of international regulation. While most agree that safety is the bottom line, few can agree on what that means, whose opinions should hold the most weight (scientists' or citizens'), or how to handle nonsafety issues such as social, economic, or ethical concerns. The FAO and WHO have a long history of multilateral efforts to promote food security and public health and have worked to develop a consensus about the implications of biotechnology for their areas of interest. Meanwhile, the IPPC and OIE are multilateral treaties that seek to protect plants and animals from the spread of pathogens through international trade, thereby providing much of the scientific consensus that underlies domestic food safety systems. Both institutions have their own nonbinding dispute avoidance and settlement systems, but their most important role in international trade is through the WTO Sanitary and Phytosanitary Agreement (SPS), which uses the IPPC and OIE standards as the basis for evaluating SPS disputes. National measures based on international standards from either of these institutions will generally not be open to challenge under the WTO dispute resolution process.

Furthermore, both the IPPC and OIE nominate experts for WTO SPS dispute panels and provide technical background information to the panels based on their standards. As such, they can have far-reaching economic and political consequences on food trade.

The Codex, under the joint FAO/WHO Food Standards Program, provides a similar service related to processed foods. The Codex develops international food standards, which identify the product and its essential composition and quality factors, identify additives

Table 2—International regulatory institutions

Institution	Members	Coverage
Food and Agriculture Organization of the United Nations (FAO)	184	Food security programs
World Health Organization (WHO)	191	Health science and policy
International Plant Protection Convention (IPPC)	107	Pests and pathogens (crops)
International Epizootics Organization (OIE)	155	Pests and pathogens (animals)
Codex Alimentarius (Codex)	165	Food standards and labels
World Trade Organization (WTO)	139	Trade rules for all goods; Dispute Settlement Mechanism
Organization for Economic Cooperation and Development (OECD)	29	Harmonize standards and policies
Regional Initiatives	Various	Harmonize science or processes
Cartagena BioSafety Protocol (BSP)	Minimum 50	Transboundary movements of living modified organisms

and potential contaminants, set hygiene requirements, provide labeling requirements, and establish the scientific procedures used to sample and analyze the product. Each standard normally takes six or more years to develop. Determination of the safety of the food product is based on scientific risk analysis and toxicological studies. Once a Codex standard is adopted, member countries are encouraged to incorporate it into any relevant domestic rules and legislation, but they may unilaterally impose more stringent food safety regulations for consumer protection, provided the different standards are scientifically justifiable. Codex plays an important role in agri-food trade because its standards, guidelines, and recommendations, like the IPPC and OIE provisions, are acknowledged in the SPS and Technical Barriers to Trade Agreements during consideration of trade disputes. There has been an eight-year process to develop a Codex standard for products of biotechnology, but consensus eludes the negotiators.

The OECD, composed of 29 industrial democracies, has actively assisted in harmonizing international regulatory requirements, standards, and policies related to biotechnology since 1985. The OECD has undertaken a number of projects to make regulatory processes more transparent and efficient, to facilitate trade in the products derived through biotechnology, and to provide information exchange and dialogue with non-OECD countries.

A number of bilateral or multilateral regional initiatives have played an increasingly important role in regulating trade in goods and services. These institutions help create the consensus necessary to establish international rules, given that many food safety concerns in trade are bilateral and the knowledge base to develop standards resides in a few countries only. The Trans-Atlantic Economic Partnership (TEP) between the United States and the EU, for example, has undertaken talks in recent years to improve regulatory processes and scientific cooperation through mutual recognition of testing and approval procedures; progressive realignment or adoption of the same standards, regulatory requirements, and procedures; the adoption of internationally agreed upon standards; and dialogue between scientific and other expert advisers in standard-setting bodies and regulatory agencies. The EU has similar trade liberalization initiatives with Canada and Japan. Since 1998 the Canadian Food Inspection Agency and the U.S. Department of Agriculture's Animal and Plant Health Inspection Service have also been studying and comparing the molecular genetic characterization of transgenic plants in search of ways to harmonize their regulatory review processes. Some agreement has already been achieved, although no formal binding bilateral agreement has yet been concluded. Meanwhile, Canada, the EU, and the United States all offer training and support for regulators in key import markets (usually developing countries) in an effort to "export" their regulatory models to other countries. These bilateral processes could be an important way to resolve technically based trade disputes. Regional agreements, memoranda of understanding, mutual recognition agreements, formal dialogues, and joint research projects are mechanisms that can be used to decrease bilateral regulatory barriers to GM food trade.

The WTO has become a focal point for examining and resolving trade disruptions related to GM foods. Although there was a nonbinding agreement on technical barriers to trade in the Tokyo Round of the General Agreement on Tariffs and Trade, the 1995 SPS agreement for the first time extended the newly formalized and binding dispute settlement system to cover trade concerns related to sanitary and phytosanitary rules and technical barriers to trade. The WTO agreement permits national "standards or regulations for the classification, grading or marketing of commodities in international trade" (Article XI) and the adoption or enforcement of measures necessary to protect human, animal, or plant life or health (Article XX(b)), but it sets some rules on when and how they may be used. Specifically, the SPS Agreement requires that measures (1) do not discriminate between member states; (2) conform where possible to international standards developed by Codex, OIE, or IPPC; (3) be based on scientific principles and the completion of a risk assessment study; and (4) do not constitute a disguised restriction on international trade.

Although the WTO is the main locus of dispute resolution for many countries, it has some limitations. As currently interpreted, the SPS Agreement allows regulations based on science but does not permit regulations that restrict trade based on nonscience concerns such as consumer preference, animal welfare, or nonmeasurable environmental risks.

The Cartagena Biosafety Protocol is one effort to

provide a more comprehensive international structure to ensure the protection of biodiversity and to facilitate consideration of nonscientific concerns in food trade. Although the Cartagena Protocol, concluded in Montreal in January 2000, is primarily designed to provide rules facilitating advance informed agreement (AIA) for first-time transboundary movements of living GM organisms intended for environmental release, it also provides for labeling (but not AIA) of GM elements in commodity shipments destined for the food chain. Countries can use this transparency to decide whether to import those commodities, but the current interpretation is that import bans must still be consistent with the WTO principles already noted. It is perhaps too early to make a confident evaluation of the protocol.

The only conclusion one can derive from this survey of international institutions is that no one institution, and perhaps not even the entire array of institutions, is likely to yield an early resolution to concerns about diverging national policies and regulations concerning GM foods.

Concluding Comments

The adoption of biotechnology and the introduction of GM foods into the international marketplace has exacerbated an already difficult area of trade policy. As biotechnology increases productive capacity in various products, it also increases the need to trade. But diverging national regulations are increasingly impeding trade in these products. This situation has begun to create production and trade distortions, which will build over time. Overcoming these distortions is made more difficult by the fact that the recent WTO agreement on agriculture is not yet fully implemented, and many of the issues left to handle are highly contentious. There is little goodwill in the policy community that can be directed to resolving the growing trade irritants caused by GM foods. As a result, a messy trade world is likely to continue. The private sector may find it needs to change how it introduces and markets the new products of biotechnology in order to maintain market access.

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RESEARCH AT A GLANCE

Biotechnology and Genetic Resource Policies

Brief 2, January 2003

Biotechnology, Trade, and Hunger

Eugenio Díaz-Bonilla and Sherman Robinson

About the Authors

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Demographers predict that the world population will stabilize some time in the second half of the 21st century. Projections by IFPRI and others show that agricultural productivity can grow fast enough to sustain the world's population, if new technologies are pursued. But there is more to feeding the world than making sure agricultural productivity stays ahead of population growth. International trade will also play a large role. Projections reveal that regions such as Africa will import a larger share of their food requirements in the future. At the same time, regions with a strong comparative advantage in agriculture will produce the additional food needed by the world.

But the new genetic modification (GM) technologies that many expect will help the world meet its food needs—not only through quantity, but nutritional quality as well—raise critical issues for international trade, including this key question: What will happen if pressure from consumers and environmentalists in the developed world leads to a new generation of trade restrictions, or to the segmentation of GM-food product markets, as appears to be happening in Europe and Japan? An answer to this question requires a brief look at agricultural trade and involves both legal and economic analysis.

Agriculture and International Trade

Currently, a large share of agricultural production is consumed in the producing countries. This is true despite major grain and oilseed exports from countries such as Argentina, Australia, Canada, and the United States, and even after accounting for major export crops such as coffee, tea, cocoa, and sugar. IFPRI and others, however, forecast a growing role for international agricultural trade in the 21st century.

There is likely to be increasing specialization in agricultural production, with more exports from countries that specialize in particular types of agriculture. Many developing countries may well hold a comparative advantage in producing high-value, labor-intensive specialty crops and horticulture, while land-abundant countries may be better at producing bulk goods such as wheat, maize, and soybeans. Research indicates that it is neither efficient nor environmentally sound for developing countries to seek food security by becoming self-sufficient in the production of food crops, particularly when such production involves inefficient, unsustainable methods on fragile lands.

GM technologies may facilitate increased specialization, while also boosting local food production and improving food security through the development of plant varieties specifically tailored to particular agroecological environments. Although the technologies have the potential to affect both traded and nontraded products, most applications to date have involved highly traded agricultural commodities.

To benefit from increases in agricultural productivity, developing countries have an enormous interest in being able to market their goods in developed countries. The world agricultural trading system is still dominated by developed countries with protected markets and domestic subsidy programs that ultimately distort international markets and potentially increase price volatility, to the detriment of developing countries.

Major goals of developing countries in the new round of World Trade Organization (WTO) trade talks should include opening markets in developed countries for their agricultural exports, including high-value, labor-intensive commodities, and reducing or preferably eliminating trade-distorting domestic policies in developed countries—especially export subsidies and price supports.

While these goals appear desirable, the picture is complicated by the possible impact of consumer and environmental concerns, particularly within developed countries, on the development of biotechnology. To consumers in high-income countries, the price-reduction benefits from biotechnology seem minor, while the unknown dangers are magnified by lack of information and mistrust in the ability of their governments to regulate the safety of the food supply.

A ban on GM products in developed countries, based on domestic consumer and environmental concerns, not only would affect market access but could also make it more difficult for developing countries to gain financial support from industrialized nations to conduct research and build human capital for biotechnology activities. Another possibility is that consumer and environmental concerns could spill over into developing countries and block or slow the development of biotechnology in those countries.

International Legal Issues

Any attempt to limit trade in GM products must be compatible with existing international legal agreements. There are only a few agreements (including environmental treaties) setting out the WTO legal framework regarding trade in GM products. These include the Sanitary and Phytosanitary (SPS) Agreement and the Agreement on Technical Barriers to Trade (TBT) of the WTO as well as a multilateral environmental agreement, the Convention on Biological Diversity, and particularly its Cartagena Protocol on Biosafety.

The question is what role these legal agreements may play in either keeping open or closing the opportunities offered by GM products. The international system is clearly under stress in this area, with growing tensions between the need for fairness in international trade and the need to respond to domestic concerns about food and environmental safety.

The Sanitary and Phytosanitary Agreement, which concerns food safety and animal and plant health, says that WTO members have "the right to take sanitary and phytosanitary measures necessary for the protection of human, animal or plant life or health." But those measures must be applied "only to the extent necessary to protect human, animal or plant life or health" and must be "based on scientific principles." The agreement also states that WTO members must "ensure that their SPS measures do not arbitrarily or unjustifiably discriminate between Members where identical or similar conditions prevail, including between their own territory and that of other Members" and, furthermore, that those measures "shall not be applied in a manner which would constitute a disguised restriction on international trade." In addition, the agreement suggests the use of international standards when possible.

The goal of all these regulations phrased in legal language is to allow countries to maintain standards of food safety but to prevent them from doing so in a way that unfairly discriminates against foreign suppliers.

The difficulty with GM products is that there are as yet no international food safety standards that really apply to them. The Codex Alimentarius defines international standards of food safety, but it does not yet specifically address GM products. Although the countries participating in the Codex are currently discussing adequate standards for GM products, a possible agreement is still some years away.

In the absence of agreed-upon international standards, some countries invoke the "precautionary principle" that allows them to set standards provisionally where relevant scientific evidence is lacking, although they are supposed to do the necessary research within a reasonable period of time. Other countries argue that the precautionary principle is being abused in order to protect less-efficient domestic producers from foreign competition. Again, the challenge lies in adequately addressing both safety concerns and fairness in trade. Currently, a review of available scientific evidence indicates that GM foods have not been found

to be unsafe—a double negative that highlights the difficulties of balancing consumer concerns, science, and international law. Proponents of GM products correctly argue that research has shown no health risks, while opponents argue that such research is not enough to prove that there are no such risks.

The basic issue continues to be market uncertainty about how consumers, mostly in developed countries, will react to GM foods. Regardless of the science, if consumers decide they do not want to consume GM goods, markets will adjust to satisfy their demands. If these negative reactions persist, markets will adjust to different scenarios of prohibition, market segmentation, and product differentiation. These market adjustments in developed countries will have an impact on developing countries.

The Economics of GM Trade

What will happen if consumers in developed countries refuse to consume GM commodities? Can world markets adjust to a complete segmentation of the markets for GM and non-GM commodities? Will developing countries still benefit from these new technologies if world markets are completely segmented and if, in addition, some developed countries refuse to adopt the new technologies at all? To provide tentative answers to these questions, IFPRI has undertaken research jointly with the Danish Institute of Agriculture, Forestry, and Fisheries Economics. Using multicountry models of world trade focused on agriculture, the research analyzes the price, production, and trade consequences of changing consumer preferences regarding the use of GM organisms in food production.

In the world model, the two primary GM crops, soybeans and maize, are specified as either GM or non-GM. This GM and non-GM split is maintained throughout the entire processing chain: GM livestock and GM food processing industries use only GM intermediate inputs; likewise, non-GM livestock and non-GM food-processing industries use only non-GM intermediate inputs. The underlying assumptions in the model are that developing countries will adopt the new technologies, to varying degrees, and that countries such as the United States will continue to use them, while Europe and Japan will not adopt them and will restrict their demand for such goods. The issue is which countries, if any, would benefit from the new technologies, to varying degrees, given the growing segmentation of the markets.

The empirical results show that global markets are able to adjust to this segregation in the sense that non-GM exports are diverted to the GM-intolerant regions, while GM exports are diverted to the indifferent regions. Price differentials are significant but tempered by commodity arbitrage. In particular, in certain GM-favorable regions, the prices of the non-GM varieties also decline because of the high degree of substitutability between the GM and non-GM varieties in domestic use and increased production of non-GM varieties to supply GM-intolerant consumers. The market results are analogous to what one would expect from increased consumer preferences in developed countries for organic foods. Such foods are more expensive to produce and command higher prices in the market. There is a gap between prices for organic and other foods, which ultimately reflects cost differences in their production and distribution. Similarly, price differentials between GM and non-GM commodities will reflect their different costs of production and distribution, with consumers who are indifferent benefiting from access to cheaper goods they find to be equivalent to non-GM goods and producers benefiting from the higher productivity of GM crops.

An important finding of this empirical analysis is that the developing countries are also responsive to GM preference changes and redirect their trade flows among partners accordingly. Furthermore, given the existing bilateral trade patterns for these particular crops, the price wedges that arise in the developing countries mainly reflect productivity differences, not preference changes in the developed world. Overall, the regions most receptive to the productivity-enhancing technology gain most, including developing countries that adopt the new technologies.

Appropriate Technology Is a First Step in Feeding the Hungry

The development of GM technology appears to hold great promise, with the potential to complement other, more traditional research methods as the new driving force for sustained agricultural productivity growth in the 21st century. Such agricultural productivity growth is crucial if the world is to produce

enough food to provide for what is likely to be a stable but large world population in this century. At this point, the many problems and concerns surrounding the new GM technologies do not seem insurmountable, just very difficult.

A world with an adequate supply of food is clearly more desirable than a Malthusian world in which food is scarce, food prices are high and rising, and people are in conflict over scarcity. Providing an adequate aggregate food supply will not eliminate malnutrition and hunger, however, now or in the future. To do that requires much more. To achieve food security for the entire world population, countries must work to reduce poverty and achieve a more equitable distribution of income—tasks that technology alone can only support, not achieve.

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http://www.ifpri.org/pubs/books/ar2001/ar2001.pdf

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RESEARCH AT A GLANCE

Biotechnology and Genetic Resource Policies

Brief 3, January 2003

Intellectual Property and Developing Countries: Freedom to Operate in Agricultural Biotechnology

Philip G. Pardey, Brian D. Wright, Carol Nottenburg, Eran Binenbaum, and Patricia Zambrano

In agricultural biotechnology, the key technologies protected as intellectual property are highly concentrated in the hands of a small number of large, multinational corporations based in North America and Western Europe ("the North"). Although many developing countries ("the South") lack the capacity to adopt these technologies, a system of international and national agricultural research centers has used them to make genetic improvements benefiting the vast majority of poor consumers. Concern is arising in the worldwide agricultural research community that the very intellectual property rights (IPRs) that have been associated with the surge of private research in biotechnology now threaten to block access to new developments to public and nonprofit researchers. This concern about current developing-country access to essential intellectual property is exaggerated and largely misdirected. The relationship between IPRs and agricultural research in developing countries is poorly understood. International and national agricultural research centers currently have far greater *freedom to operate*—the ability to practice or use an innovation—in agricultural research on food crops for the developing world than is commonly perceived.

The Misperception of IPRs

Even in developed countries, private sector agricultural research efforts concentrate primarily on a small number of crops with high commercial value. For the vast number of other crops, public and nonprofit institutions are the principal source of genetic innovation in the foreseeable future. In developed countries these institutions increasingly find their access to essential innovative inputs uncertain, unduly expensive, or at times blocked altogether (Wright 1998; Lindner 1999).

Given the minor role of the crops involved, this problem is a source of aggravation and inefficiency in the North but is in no way a serious threat to the well-being of consumers. Understandably, the international research and donor communities fear that the problems of access to intellectual property (IP) experienced in the North constitute a serious threat to the supply of food and fiber to the poor in the South. Many of the world's poor rely for sustenance on crops such as rice, beans, and cassava, which are largely beyond the focus of the private research sector and have modest commercial prospects due to low income elasticities. When major multinational corporations made some well-publicized "donations" of intellectual property to developing countries for certain noncommercial crops, they not only highlighted the usefulness of these tech-

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nologies, but also reinforced the impression of a general lack of access to modern technological opportunities for these crops.

The Consultative Group on International Agricultural Research (CGIAR) and other international and local agricultural research organizations are still supporting and conducting agricultural research and development (R&D) geared toward poor farmers and consumers, as they did during the Green Revolution. The research budgets of many of these agencies, however, are now dwarfed by those of the major corporations in the field. Major donors have encouraged the CGIAR and other international and local agricultural research organizations to negotiate with major corporations to gain access to technologies for use in agricultural research conducted in or for developing-country economies. A survey shows fairly widespread use of protected IP by CGIAR centers, in many cases without formal authorization from the patentees (Cohen et al. 1998). While confirming the extent of international researchers' use of biotechnologies, this study showed researchers to be confused about relevant IPRs and created a sense of urgency about the regularization of licensing or other IPR transfer arrangements.

In fact, IPRs are based primarily on national laws. Public and nonprofit agricultural researchers generally have freedom to operate in regions where most modern technologies are unprotected by national IPR laws. Production in the South of a crop protected only in the North is both legal and moral per se (Barton and Strauss 2000; RAFI 2000). If, however, there is significant international trade in agricultural commodities and international transfer of the technologies used in their production, identifying valid IPR concerns becomes more complex. Thus, the spatial aspects of intellectual property are pivotal to freedom to operate in agricultural research.

The Rights to Research

The principal public policy rationale for protection of intellectual property is that it provides direct, socially beneficial incentives to innovate, while also facilitating further innovation by mandating public disclosure of the patented technology. When individuals or organizations know that legal protection will enable them to recoup their research investments, they have a stronger incentive to pursue such innovations. In the absence of protection, attempts to recoup investments or to profit commercially from an innovation may fail because of imitation. Knowing this, prospective innovators may underinvest in R&D or exploit their inventions in secret. In addition, by clarifying rights to new ideas, intellectual property protection helps to reduce the costs that would otherwise be required to determine ownership of rights.

An important but perhaps underappreciated aspect of most systems of IPRs is the requirement that inventors and researchers seeking these rights disclose the new knowledge they have obtained. As new ideas are disseminated through publication, licensing, or other means, this information stimulates further rounds of innovation and technological advances.

Inherent in intellectual protection is a tension between the goal of providing incentives for innovation and that of allowing innovators to build upon one another's work. The broader the monopoly rights conferred, the larger the potential threat to the freedom to operate. Owners of a technology may be unwilling to share or license it or willing only after costly negotiations, thus making it difficult for others to obtain essential tools for advancing their own research. Moreover, owners of technology may litigate against alleged infringers, so in practice, those who hope to use a protected technology must weigh the risk of litigation against the costs of obtaining licenses.

To further complicate matters, the modern methods used to develop new crop varieties depend on a wide range of component innovations, the rights to which may be held by many competing parties—be they patent rights or use rights assigned through commercial contracts or licenses. And the number of separate rights needed to produce a new innovation will only escalate as biotechnology patents become more prevalent. If ownership of these rights is diffuse and uncertain, it can be difficult or impossible for potential users to successfully negotiate with all of the relevant parties.

Yet agricultural researchers in many developing countries are freer than one might think to make use of innovations protected in the developed countries. This is because there is no such thing as an "international patent right." Patent or other rights awarded in, for example, the United States do not *a priori* confer property rights in the rest of the world. Patents and other IPRs are awarded by national governments, and

the protection conferred by each national government applies only within that country. To obtain patent protection in several countries, innovators must apply for and gain rights in each. Table 1 shows some key agricultural biotechnologies and where they are subject to intellectual property protection. In countries where a technology is not subject to intellectual property protection, anyone is free to make, use, or sell whatever technology or knowledge is available for crops, irrespective of whether the crop is grown for subsistence or commercial use or the technology is protected elsewhere.

Table 1—Property protection status of some key agricultural biotechnologies

Technology	Property rights holder	Jurisdiction	Patent numbers
The key agrobacterium technology for plant transformation			
	Monsanto	Australia, Europe, Japan (pending), Russia, and United States (in interference)	Australian patent 559,562 B2; European patents 131,620 B1 and 131,624 B1; former Soviet Union patent 1,582,990 A3
	Max Planck Institute	Australia, Denmark (pending), Europe, Israel (pending), Japan, and United States (in interference)	Australian patent 546,542 B2; European patent 116,718 B2; Japanese patents 2,769,539 B2 and 2,726,267 B2
	AstraZeneca/Mogen	Europe, Japan (pending), and United States	European patent 120,516 B1; U.S. patents 4,940,838 and 5,464,763
	Novartis	United States	U.S. patent 6,051,757
	Japan Tobacco	Australia, Canada (pending), Europe, Japan, and United States	Australian patents 667939 B2 and 687863 B2; European patents 604662 B1 and 672752 B1; Japanese patent 2649287 B2; and U.S. patent 5,591,616
The most widely used selectable markers for cereal transformation			
Phosphinothricin, Basta®	Aventis/AgrEvo	Australia, Canada, China (pending), Europe, Finland, Greece, Hungary, Israel (pending), Japan (pending), Mexico (pending), New Zealand (pending), Singapore, South Africa (pending), and United States	Australian patents 653,845 B2, 613,367 B2, 609,082 B2, and 604,743 B2; Canadian patents 1,337,597 A1 and 1,321,364 A1; European patents 531,716 B1, 290,986 B1, 275,957 B1, and 257,542 B1; Finnish patent 100,251 B1; Greek patents 3,007,859 T3 and 3,005,200 T3; Hungarian patents 216,645 B, 217,208 B, and 215,079 B; Singaporean patent 46,682 A1; U.S. patents 5,767,371, 5,767,370, 5,668,297, 5,650,310, 5,077,399, 5,637,489, 5,276,268, and 5,273,894
Kanamycin resistance gene or G418 under control of CaMV 35S or 19S promoters	Monsanto	Europe and United States	European patent 131,623 B2; U.S. patents 5,034,322 and 6,174,724
Hygromycin resistance	Novartis	Australia, Canada, Denmark (pending), Europe, Finland (pending), Greece (pending), Hungary, Ireland, Israel (pending), Japan, Russia, and United States	Australian patents 555,574 B2, 582,653 B2, and 565,625 B2; Canadian patents 1,195,626 A1 and 1,278,540 A1; European patents 68,740 B1, 135,291 B1, and 186,425 B1; former Soviet Union patent 1,250,174 A3; Hungarian patents 195,248 B and 200,366 B; Ireland patents 8,853,521 B and 9,357,776 B; Japanese patent 2,815,837 B2; U.S. patents 4,727,028, 4,960,704, and 5,668,298
CaMV 35S promoter	Monsanto	Europe and United States (Rockefeller University)	European patent 131 623, currently being opposed; U.S. patents 5,352,605, 5,530,196, and 5,858,742

Source: Search conducted by Carolina Roa-Rodríguez for authors using the CAMBIA-IP online patent database.

The extent of freedom to operate in developing countries is not well understood. For example, the recent vitamin A rice innovation (*Golden*rice™) reportedly requires permission to practice more than 70 patent rights. The well-publicized donations by major corporations of their intellectual property relevant to vitamin A rice left a strong impression that they were relinquishing the exercise of large numbers of crucial patent rights in favor of the poor in developing countries. In fact, in some major rice-consuming countries, there are no valid relevant patents, and in most, there are very few. Similarly, the donations of virus-resistant technology for some noncommercial potato varieties in Mexico and for sweet potato in Africa apparently do not involve any patents relevant in the target countries. Finally, the Cohen et al. (1998) survey reported fairly widespread use of protected intellectual property by the centers of the CGIAR, in many cases without formal authorization from the patentees. But no distinction was drawn between patents valid in developed countries and those valid in the centers' host countries.

Though there is no international patent, international treaties and organizations do play an important role in IPR. They make it easier to extend protection to multiple countries and provide a uniform, minimal set of laws and standards that apply to all subscribing countries. Increasingly, innovators in developing countries are seeking IPRs in developed countries, and vice versa. Currently, however, in the fields of agriculture and agricultural biotechnology, the type and scope of protection varies greatly from country to country, especially between developed and developing countries. This variation makes it more difficult to assess whether there is freedom to operate on an international level.

How Production and Trade Patterns Affect IPRs

Understanding the production and trade status of crops relevant to developing countries is important not only in ascertaining the implications of IPRs, but also in assigning use rights by the private sector to public and nonprofit plant breeders. The willingness of owners of agricultural technology to cede use rights, or the minimum price at which they are willing to sell the rights to others, is shaped—among other things—by where crops are produced and traded.

Developing-world crop breeders have freedom to operate with respect to crops produced in developing countries unencumbered by local intellectual property protection of relevant inputs, processes, or products. Problems may arise, however, if those crops are subsequently exported in a form in which infringement is detectable to countries in which intellectual property protection is likely to prevail. In such cases it is the importer, not the breeder, who may be infringing on intellectual property. Binenbaum et al. (2000) studied production and trade data for 15 of the crops most important to research agencies operating in developing economies (soybeans, bananas, rice, coconuts, groundnuts, wheat, cassava, maize, beans, potatoes, chickpeas, sorghum, lentils, millet, and barley). The findings suggested the extent to which trade patterns are likely to raise IPR problems for agricultural research in developing countries:

- Exports from developing to developed countries of CGIAR crops are insignificant compared with total agricultural exports from developing countries, developed-country imports, or even domestic agricultural production, except for a few commodities and a few developing countries.
- As a group the developing countries account for more than 90 percent of the world's production of rice, millet, cassava, sweet potatoes, yams, bananas, plantains, chickpeas, cowpeas, pigeon peas, groundnuts, and coconuts (and for quite a few of these crops they account for more than 98 percent of production). They also account for more than 65 percent of the world's production of sorghum, beans, and lentils.
- For the majority of CGIAR crops, output is never traded across international borders. Soybeans, coconuts, bananas, lentils, and beans are the only crops of the 15 studied for which more than 10 percent of developing-country production is exported.
- Just two crops (soybeans and bananas) account for 64 percent of developing-country crop exports to the developed countries, and just four countries (Argentina, Brazil, Costa Rica, and Ecuador) account for 42 percent of the South-North trade in these two crops. Adding exports of rice and coconuts amounts to 80 percent of the South-North trade total, with most of the rice coming from Thailand and coconuts from the Philippines.
- The principal destination for South-North trade in 9 of the top 10 developing-country crop exports

(specifically soybeans, bananas, rice, coconuts, groundnuts, cassava, maize, beans, and potatoes) is Western Europe. Wheat is the only exception. To the extent that it is exported from developing countries, it is mainly shipped to North America and Japan. These exports are dwarfed, however, by wheat trade from North America to developing countries.

The trade data suggest that freedom-to-operate problems are most likely to arise in soybeans, bananas, and rice, but soybeans are not currently a major focus of public research by national or international agricultural research organizations working in or on behalf of the developing world. There is still substantial freedom to operate, however, for most crops of major significance for food security in poor countries. While freedom to operate in specific circumstances depends upon the claims of the IPR and its spatial pattern, crop production, and trade, IPRs over biotechnologies are mainly held in rich-country jurisdictions and are therefore primarily relevant to these jurisdictions.

IPRs in the North affect farmers in the South if they export infringing products in detectable form to the North. South-North trade in food staples is limited overall, however, and involves only a few crops and developing countries in any significant way. IPR-based limitations on export markets for food staples that embody technologies protected only in the North should not in general be considered an important impediment to the use of these technologies in such crops in the South.

This does not mean that freedom to operate is no problem for developing-country research on export-oriented cash crops such as horticultural products, tropical beverages, or dessert bananas. The Binenbaum et al. study (2000) focused on the predominant food crops of significance to poor people.

Focusing on More Urgent Problems

Undue concern about the freedom to conduct research by or on behalf of developing countries is misdirecting policy and practical attention away from the main constraints currently facing researchers on food crops for the South. The real constraints are an increasingly serious lack of investment in developing-country research and a lack of local scientific skills to access the rapidly advancing stock of complex modern biotechnologies, whether they are protected by patents or not (Pardey and Beintema 2001). Biotechnology is challenging the adaptive capacity that has enabled poor countries to benefit from the advances in plant genetics and other relevant technologies in the past half-century, and lagging public resources are not being replaced by private-sector investments. Failure to invest in the adaptive capacity needed to evaluate, access, and regulate the technologies being developed in the North is currently a far greater constraint than IPRs. The very confusion over this issue illustrates researchers' and decisionmakers' lack of capacity to handle questions relating to IPRs and freedom to operate in developing-country plant breeding.

For the future, how the World Trade Organization's Agreement on Trade-related Aspects of Intellectual Property Rights (TRIPs Agreement) is implemented with respect to plant-breeding technology, domestically and in important export markets, is a crucial issue for developing-country policymakers. Where patenting of plant and other life forms is allowed, the patenting of key biotechnologies in the South will grow, threatening developing-country researchers' freedom to operate and freedom to trade in developing-country agricultural products, both South-North and South-South. This issue ranks with implementation of farmers' rights as an important policy concern for plant breeders, farmers, and the food consumers of the South. But *domestic* freedom to operate is generally the relevant IPR issue; exports of food staples that dominate agriculture are not important growth drivers in most developing countries.

Private corporations in the developed countries spent nearly US$11 billion on agricultural R&D in 1995 (in 1993 prices). By misunderstanding their present freedom to operate, breeders of food crops for the South threaten their ability to bargain effectively for access to the scientific outputs from OECD countries. As institutional innovations bridging the private-public divide begin to emerge (Nottenburg et al. 2002), all parties need a clear picture of the present degrees of freedom regarding Southern agricultural R&D in order to strike effective deals when tapping Northern intellectual property on behalf of the world's poor, to know when such deals are not needed, and to recognize what is being surrendered in choosing patenting rather than plant breeders' rights in implementing the TRIPs Agreement.

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RESEARCH AT A GLANCE

Biotechnology and Genetic Resource Policies

Brief 4, January 2003

Accessing Other People's Technology

Carol Nottenburg, Philip G. Pardey, and Brian D. Wright

Public and private nonprofit institutions worldwide engaged in agricultural research and biotechnology are increasingly active participants in intellectual property transactions, interacting with the for-profit sector and even spawning private entities of their own. Notably absent from the group of nonprofit institutes seeking patent protection are the 16 centers of the Consultative Group on International Agriculture Research (CGIAR). Located primarily in developing countries, only a few centers have obtained patent protection for their inventions.

Nonprofit research institutions are not in the business of selling products to consumers. If they are to realize a return on their investment, they must sell rights to their technologies to commercial entities or other research institutions rather than make them freely available. A nonprofit entity may, for example, exclusively license technology to a commercial partner, license the technology itself nonexclusively, or use the technology as the foundation for a spin-off company.

For all the benefits that nonprofit institutions receive from intellectual property, these same institutes are notorious for using other people's patented technologies without permission. A review of the intellectual property policies of several large universities in the United States with active licensing offices reveals that none discusses the need to obtain permission to use patented methods and materials, and only one provides guidelines on copying material that is copyright protected (Nottenburg, Pardey, and Wright 2002). In contrast, for-profit entities—especially in biotechnology—are not only generally more cognizant of intellectual property rights and rules, but also proactive in obtaining licenses, options for licenses, or collaborations that will assure their "freedom to operate," that is, their ability to practice or use an innovation.

Nonprofit research organizations need to develop and implement policies regarding use of other people's technologies. With a special emphasis on agricultural biotechnology, this brief discusses policies of intellectual property protection, de jure (by right) and de facto research exemptions, and the ways that research at nonprofit institutes fits with, and is at odds with, these policies and exemptions. We also present an overview of the steps necessary to abide by others' intellectual property rights (IPRs) and show how most nonprofits are ill equipped to undertake such measures. Finally, we present strategies for pursuing different options to obtain rights to use other people's technologies.

Protecting Intellectual Property

The major forms of legal protection available for agricultural biotechnology are patents, plant breeders' rights (known in the United States as Plant Variety Protection Certificates), trademarks, trade secrets, and contracts. Third-party trademarks and trade secrets, however, have relatively little impact on nonprofit institutions and so will not be discussed here.

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Protecting and controlling the use of intellectual property can also be achieved by technical means, like hybridization of crops such as corn and rice and genetic use restriction technologies (GURTs). These methods have the greatest impact on farmers by rendering the seed unsuitable for replanting or suppressing the expression of certain introduced traits in saved seed. They are dealt with in detail by UNEP/CBD/SBSTTA (1999).

A web of proprietary claims now envelops the transfer and use of patented biotechnologies, thereby limiting the freedom to operate of public and private agencies alike. Biotechnologies covered by these claims include (1) parent germplasm in the form of individual plant varieties; (2) germplasm constructs that include trait-specific genes; and (3) transformation technologies, such as a gene coding for a specific characteristic inserted into plant cells, selectable markers, and gene silencing or regulating technologies. Depending on the complexity of the transgenic product, dozens of identifiable proprietary claims can be involved in its development.

Patents

Patents protect inventions of tangible things and confer a legally enforceable right on their owners to exclude others from practicing the invention described and claimed in the document. These rights apply for a limited period of time, generally 20 years, and only in a specific legal jurisdiction.

A common misconception is that a patent awarded in one country confers rights in the rest of the world. This is not so; there is no such thing as an "international patent." Patents are awarded by national governments, and the protection conferred by a patent extends only to the national jurisdiction in which the patent is awarded. To protect an innovation in more than one country, a patent must be awarded in each. The cost of obtaining a patent varies from country to country, and the cost of obtaining protection in every important market can be substantial. In general, most inventions are patented in just one or a few countries, mainly the developed ones.

Plant Breeders' Rights

To be granted a plant breeders' right (PBR), an applicant must demonstrate that the variety is new, distinct from other varieties, and genetically uniform and stable through successive generations. The holders of a PBR have a legal monopoly over commercialization of their variety for a prescribed length of time. Generally, PBRs encompass the right to sell, reproduce, and import a new plant variety. PBRs in most jurisdictions contain a research exemption.

Forms of PBRs consistent with the International Union for the Protection of New Varieties of Plants (UPOV) now exist in most developed countries. Developing countries are adopting either UPOV standards or other forms of plant variety protection to comply with the requirement of the Trade-Related Aspects of Intellectual Property Agreement (TRIPs) to grant a so-called *sui generis* form of protection to plant varieties. By December 2001, 50 countries (including, most recently, Bolivia, Brazil, China, and Kenya) had enacted PBR legislation.

Permission Issues

The nature of the patent right allows the patent holder to exclude others from making, using, selling, offering for sale, or importing the patented invention. To encourage basic research, countries have sought to facilitate access, either through a statutory exemption, a common law exemption, or compulsory licensing.

In the United States researchers generally assume that patent law does not apply to their basic research. Academic researchers are often shocked to discover that, except for some limited statutory exemptions, there is no general research exemption for using other people's patented technologies. Courts generally have ruled that using another's invention for research or experimental use is an infringement. Research at a university or other nonprofit institution, even if performed without any profit motive, would constitute an infringement.

The U.S. Congress has enacted only a few narrow exemptions. Yet there does appear to be a de facto exemption in the United States. Even absent a legal research exemption, it is unlikely that nonprofit institutions have more than a minor risk of infringement exposure, especially in cases where the nature of the research is clearly noncommercial. The number of patent suits filed against nonprofit organizations in U.S. District Courts is extremely small.

Commercially Oriented Research

The risk of infringement liability may be higher when commercially oriented research or services are

involved. In these cases the unauthorized user may receive a letter requesting that the activity cease and desist, an offer for a commercial license, or notice of an infringement action.

An important trend, however, is that the line between nonprofit and commercially oriented research is becoming blurred. An increasing amount of research is performed as part of private-public sector alliances. Substantial private sector funding also supports research conducted by government agencies and public universities in many developed countries, and in some developing ones as well. Public policies have encouraged this. In the United States, for example, the Bayh-Dole Act of 1980 mandated that the U.S. government cede ownership of intellectual property emanating from government-sponsored research to the recipient institutions. Under the auspices of Cooperative Research and Development Agreements (CRADAs), specifically designed to speed the commercialization of federally developed technology, the government and its collaborating partner may share patents and patent licenses, allow one partner to retain exclusive rights to a patent, or assign licensing rights to facilitate licensing to third-party users.

What Is "Free Access"?

Given the risk of using other people's patented technologies, some in the nonprofit research world may want express permission to use the technologies. Permission may be obtained in a variety of ways, but the recipient should be vigilant in identifying the hidden costs of access. Sometimes agreements widely characterized as onerous are actually far less restrictive than apparently "free" deals and traditional consulting arrangements between private firms and individual academics.

Determining Freedom to Operate

As nonprofit research becomes more commercially oriented, the risk of serious consequences for infringement may well increase. As risk increases, the need to scrutinize the intellectual property landscape and the freedom to operate will become more pressing. There are various reasons why determining freedom to operate can be a daunting task, especially for the nonlegal professional.

- A freedom-to-operate analysis is, by design, a snapshot of the current patent situation; however, patenting and disclosing inventions is a dynamic process. A review of emerging publications is integral to such analyses given the continuous stream of patents and applications being published.
- The challenges inherent in an ever-changing landscape are further complicated by the difficulty of determining which entity will triumph, and with what claims.

A patent's claims—not its text—define the parameters of the patent right conferred on the patentee. Hence, to delineate the extent of the right, a potential user must interpret these claims. In the United States claim construction is a matter of law and centers on an objective test of what a person of ordinary skill in the art at the time of the invention would have understood the claim to mean. Infringement is determined by examining whether the alleged infringing product or method falls within the scope of the claims.

The development of any product in biotechnology requires a multitude of technologies and reagents. This is especially true in agricultural biotechnology, where the delivery system includes germplasm. Typical reagents include vectors for transformation of plants, components of vectors, elite plant varieties, and the like. In the case of *Golden*Rice™, an analysis estimated that 70 patented technologies were used during research and development (R&D). This analysis illustrates the complexity of intellectual property in agricultural biotechnology.

Several databases with differing amounts of information are available on the Internet; some are available by paid subscription and some are free. For nonlegal professionals, a problem common to all the existing databases is the interface, which caters to individuals with a substantial knowledge base concerning intellectual property. Furthermore, with the exception of the database of the Center for the Application of Molecular Biology to International Agriculture (CAMBIA; see www.cambiaIP.org), none provides an explanation about patents, how to read a patent, or other information to assist the naïve user.

Options for Gaining Access to Other People's Technology

Various options are available for gaining access to proprietary technologies. Some of the more important

ones are discussed here, mainly from the perspective of a nonprofit agency. This discussion emphasizes developing countries, although most of the issues are relevant in developed countries too.

Cross-Licensing

At CGIAR centers, licensing would have to be restricted to property other than landraces and other plant varieties designated as "in trust" material (under a 1994 agreement with the Food and Agriculture Organization of the United Nations) that must be made available to the world at large. Through a material trust agreement (MTA), recipients of in-trust material distributed by CGIAR centers agree not to seek intellectual property protection on that material, though they may seek protection for derivatives.

Despite these severe constraints, candidates for cross-licensing have already been identified. The near-isogenic lines of rice germplasm potentially useful in plant breeding and developed at the International Rice Research Institute are examples of plant breeding that might be licensed via an MTA or other contractual agreement. Fischer and Barton (1999) proposed a model MTA in which a CGIAR center would offer such material to another institution at no cost in exchange for access to information about subsequent discoveries and zero-cost nonexclusive research licenses to CGIAR centers and agricultural research agencies operating in developing countries. If this example leads to successful cross-licensing, it is likely to be the exception that proves the rule. The number and value of intellectual property resources held by most public agencies operating for developing countries are often overstated, which puts them in a relatively weak negotiating position.

Research-Only Licenses

A free research license that does not permit commercialization can make a research tool the "cuckoo's egg" of technology transfer. If the project succeeds, then the bargaining for permission to commercialize must begin. On the one hand, researchers have already incurred the sunk cost of all the research, placing them in a highly disadvantageous bargaining position. On the other hand, even in refusing to allow commercialization, the IPR holder gains valuable information about the technology and its downstream applications.

Market Segmentation Strategies

All CGIAR centers engaged in biological research are in developing countries. Patents are usually filed in, at most, a select group of countries. Indeed, until recently few developing countries allowed patents on life forms. To the extent that research agencies use technologies and cultivars that are not patented or otherwise protected where the agencies are located, they can and should legally proceed without obtaining permission from the IPR holder. Even after compliance with TRIPs, the breeding of new cultivars using prior cultivars protected in developed countries may be legal under the sui generis protection that is being adopted in many developing countries.

The new regime of the World Trade Organization (WTO) might facilitate a kind of indirect market segmentation, in which developing countries get the new technology for free, and proprietary claims are enforced in developed countries. Further, cultivars incorporating genes patented in developing countries may not be subject to effective intellectual property claims if those countries have neither the legal means nor the will to enforce them.

In the near term, research agencies in developing countries are likely to have considerable freedom to operate, if they operate judiciously. Because retroactive patenting is impossible, most of the technologies usable by the CGIAR and its developing-country partners over the next half-decade or so are likely to be unencumbered by relevant intellectual property rights. Mistakes, however, could result in catastrophic legal liability. To reliably implement a strategy of obtaining intellectual property only where necessary, those who make research commitments must have access to adequate information and to expert legal counsel. Such access does not exist for most developing-country researchers and research institutions.

A promising initiative to provide intellectual property information services for developing-country organizations is being pursued by the Australian nonprofit corporation CAMBIA. The aim is to develop interactive software that can help researchers identify prior patent claims and areas of freedom to operate and thus travel more safely through the international patent minefield. If adequately funded on a continuing basis, such an initiative could reduce the uncertainties about prior claims to useful biotechnology.

Markets for intellectual property can also be segregated on grounds other than geography. With technology licenses, common segmentation strategies include delineating fields of use, length of time, certain claims of a patent, limitations to specific uses of the technology, research use versus commercialization, or restrictions on third-party services. Another option is to charge license fees based on an ability to pay or expected profit streams.

Mergers or Joint Ventures

Mergers can be a way to avoid an expensive patent fight. In agricultural biotechnology, mergers are a prime private sector solution to minimize the private costs of transactions in intellectual property. Mergers and outright privatization of previously public research agencies are characteristic of public sector agricultural R&D reforms in countries such as the Netherlands and the United Kingdom. But much of this change seems to have been driven by policy reforms and public budget cuts, not by a consideration of intellectual property.

Joint ventures are often viewed as a more promising and flexible alternative. For example, Monsanto is marketing transgenic cotton in China in a joint venture with a provincial public seed-producing organization.

Cost-Free Licensing of Technologies

For many minor crops, private and public IPR holders might be persuaded to allow international agricultural research centers and public research agencies in developing countries to develop proprietary biotechnology for use by farmers without any direct compensation. This situation is more likely where there is obviously little risk to the significant commercial markets that are the focus of the IPR holders' hopes for profits. Such cases have already occurred in these noncommercial crops, including several under the auspices of the International Service for the Acquisition of Agri-Biotech Applications (ISAAA).

Direct Programmatic Research Support from the Private Sector

For-profit corporations might be persuaded to give more general support to collaboration with public research. Important examples of such support on the part of corporations with significant market power have already occurred. In the genomics field, a consortium of corporations has supported creation of a public database of genome markers in preference to partaking in a competing private sector initiative. Such cases suggest that private firms might, on occasion, choose to support public or private research initiatives in areas complementary to their own endeavors.

In another case Monsanto donated technology for the transformation of corn by *Agrobacterium* to the University of California. As part of a divestiture of assets ordered by the U.S. Justice Department, Monsanto was persuaded to give this technology to the university, allowing the university to license access to the technology to third parties. The details of this case illustrate the important point that prospective recipients must exercise flexibility and initiative to take advantage of such opportunities.

Patent Pools

A patent pool is an aggregation of intellectual property rights that are cross-licensed and licensed to third parties. In the United States the two critical features of a patent pool are that (1) the pool integrates complementary patent rights, and (2) the resulting competitive benefits are likely to be outweighed by competitive harm posed by other aspects of the program. Thus, patents in the pool must be essential to practice the technology.

Such joint agreements are probably not feasible as a regular modus operandi for pooling agricultural biotechnologies on a one-by-one basis. A better option is to coordinate a joint commitment by the major biotechnology providers and public agencies (including the CGIAR) to provide royalty-free licenses on all IPRs in agreed terms of application. In negotiating and drafting any such agreement, attention should be paid to national antitrust laws. This type of negotiation is difficult and costly to all parties and requires high-quality legal advice.

Clearinghouse Mechanisms

An alternative means of lowering the cost of technology transactions in biotechnology is the creation of an Internet-based clearinghouse (Graff and Zilberman 2001). This clearinghouse could identify relevant intellectual property in specified technology endowments, its availability, and how it could be obtained. It could also establish prices or pricing indicators, facilitate negotiations, and offer mechanisms for arbitration of disputes and monitoring of compliance. An agricultural biotechnology intellectual property clear-

inghouse could bundle together sets of complementary patents from different patent holders into complete "biotechnology or agronomic systems" contracts. Through such strategies, it would be possible to create customized licenses that could greatly increase the use of inventors' technologies and make multipatent technology systems readily available and affordable to researchers.

Independent Development of Research Tools

A quite different approach is to sponsor the creation of substitutes for existing proprietary research paths. For example, CAMBIA seeks to generate new biotechnology tools for agriculture, unencumbered by restrictive property claims. These tools are in turn made available on an ability-to-pay basis. The licensing revenues are used to fund further research and to support transfer of the technologies to developing countries.

Pressure for Sharing of Technology

International research institutions, including the CGIAR and FAO, should continue to press for including the interests of international and developing-country nonprofit research collaborations in measures designed to address the interests of domestic research institutions in the leading countries.

One form of pressure is a boycott of companies demanding "unreasonable" terms for key enabling technologies. Making common cause with more powerful allies in applying pressure on IPR holders might help ensure that any concessions by IPR holders are extended to nonprofit international agricultural research and that intellectual property is disseminated to noncommercial markets.

Conclusion

Designing policies and operating procedures to ensure that public science has sufficient freedom to operate is becoming increasingly important in the developed and developing worlds. Freedom to operate will be crucial for public and nonprofit agencies intent on developing improved seed varieties and other technologies destined for commercial release, albeit in markets that may generate large social gains but are not necessarily privately profitable. Various options are available to improve the efficiency of public-private relationships—particularly options that could lower the transaction costs of tapping proprietary technologies to further public research. Paradoxically, for developing countries the short-run importance of freedom to operate has been exaggerated by well-publicized donations that generate inferences that the multinational life science oligopoly holds extensive portfolios of intellectual property that block further research in those countries. Ironically, in developed countries nonprofit researchers often believe themselves exempt from infringement suits. Worldwide, institutions need to better understand their rights and responsibilities regarding intellectual property.

As things stand now, intellectual property does not appear to be the binding constraint on science in developing countries, but it is becoming a constraint on nonprofit research in rich countries. The real problems facing many countries and agencies, especially in developing countries, are lack of local investment in science and limited experience and expertise in gaining access to, using, and regulating modern biotechnologies. Developed countries are not immune to these problems either. Also suffering are the agricultural biotechnology industries in developed countries like Australia and Canada, which have comparatively small investments in domestic R&D but are highly dependent on exports to countries that have strong intellectual property protection (such as the United States and European countries). Furthermore, the implementation of TRIPs as currently formulated will likely affect the freedom to operate in the next generation of biotechnologies. Guiding these changes in intellectual property regimes and responding creatively to the new environment are pressing challenges for those interested in the future of scientific research, including agricultural biotechnology.

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RESEARCH AT A GLANCE

Biotechnology and Genetic Resource Policies

Brief 5, January 2003

Infringement of Intellectual Property Rights: Developing Countries, Agricultural Biotechnology, and the TRIPs Agreement

Konstantinos Giannakas

Parallel revolutions in molecular biology and intellectual property rights over plant genetic resources helped spur the emergence of agricultural biotechnologies and the introduction of genetically modified (GM) products into the food system. Intellectual property rights create economic incentives for research and development by giving innovators claim to the benefits associated with new technologies. Yet although intellectual property rights (or IPRs) purport to protect intellectual property, innovators may not always be able to fully appropriate the benefits associated with the innovation.

When it is profitable for technology users to infringe on IPR, their compliance with IPR provisions is by no means assured. Costly monitoring and enforcement are required to deter unauthorized use of the new technology. Experience from various countries around the world shows that the enforcement of technology use contracts (between technology providers and farmers, for example) and other means of protecting intellectual property is far from perfect, and most, if not all, successful innovations are subject to piracy. This is particularly true in developing countries, where opposition to the very granting of IPRs for agricultural crops is growing. In addition to monopolistic rents transferred to foreign IPR holders, concerns of developing countries include environmental safety and food security. The result is a widespread violation of innovators' rights in these countries, which has become a major international issue.

Concerns about the protection of intellectual property led to the Agreement on Trade-Related Aspects of Intellectual Property (TRIPs) during the Uruguay Round of negotiations for the General Agreement on Tariffs and Trade (GATT). Under this agreement, administered by the World Trade Organization (WTO), innovators in one country whose rights are being violated in another country have a means of defense through a dispute settlement mechanism. Within the next few years the agreement is scheduled to be fully in force among all WTO members, including the poorer countries that were given some leeway in putting intellectual property legislation in place and into practice. The magnitude of fines to be imposed, however, has yet to be determined.

While innovators have actively lobbied for the effective enforcement of their rights, their pricing behavior reveals preferential treatment of customers who least respect their intellectual property. Multinational firms claiming rights usually charge significantly lower prices for the use of protected technologies in markets with lax IPR enforcement than in markets with effective enforcement. In Argentina, where 50–85 percent of the Roundup Ready© soybean seeds grown are either purchased from the "black" market (25–50 percent) or saved by farmers from the previous year's crop (25–35 percent), the

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prices charged by the innovating firm (Monsanto) are less than half those charged to U.S. soybean producers (U.S. General Accounting Office 2000). This discrepancy raises concerns among U.S. producers, who feel they are being penalized for their "honesty." And they are probably right.

This brief examines the economic causes of IPR infringement by agricultural producers that use the products of biotechnology, and the effects of such infringement on the pricing and adoption of new technology and the well-being of various special interest groups. Specifically, I analyze the unauthorized use by farmers of GM seed developed and produced by a foreign company and intellectual property protected in certain, especially developing-country, markets.

Causes and Consequences of IPR Infringement

The more likely farmers are to profit from IPR infringement, the less likely they are to comply with IPR provisions: the possibility of purchasing black market seed at a lower price or using farmer-saved seeds may be economically optimal for producers, in which case they may proceed to use the technology without paying the associated fee.[1] The decision by farmers not to comply with the provisions of an innovator's rights, as well as the extent of infringement, depends on the degree of IPR enforcement in the developing country. The lower the penalty for IPR infringement, or the lower the probability a producer will be detected using GM seed illegally, the greater the expected gains from cheating and the more extensive the likely IPR violation will be.

IPR infringement affects the well-being of both agricultural producers and innovators and has important ramifications for the pricing and adoption of new technology in developing countries (Giannakas 2002). The purchase of GM seed from the black market and the use of farmer-saved seed reduces the GM seed demand for the innovator. Since IPR infringement reduces the demand for GM seed in the developing country, it reduces the price of the new technology and the economic rents that can be extracted by the innovator or IPR holder. The greater the extent of IPR infringement, the lower the innovator's ability to obtain value for its biotech traits.

The reduction in price of new technology under imperfect IPR protection means that while IPR infringement reduces the economic rents accruing to the innovator, it increases the well-being of all biotechnology users in the developing country—both those who use the GM seed illegally and those who purchase the GM seed they use. "Honest" producers benefit from the lower price charged by the innovator in the presence of IPR infringement. Thus the result of imperfect enforcement of IPRs is an increased adoption of the GM technology in the developing country.

Determinants of IPR Enforcement

Consider the decisions of developing-country governments ("domestic governments" hereafter) responsible for enforcing an innovator's intellectual property rights. Since IPR infringement increases the well-being of domestic agricultural producers while reducing the economic rents earned by innovators, the level of enforcement in a developing country is determined by the political preferences of the government. Strictly speaking, the less importance domestic governments place on the rents going to a foreign innovator, the lower the level of IPR protection and the lower the innovator's ability to obtain value for its biotech traits.

When a government does not consider the effect of its choices on the economic rents accruing to foreign innovators, its optimal choice is to allow complete, unauthorized use of the GM seed. Allowing IPR infringement maximizes the well-being of domestic producers and leaves enforcement costs at zero. Moreover, when domestic governments are indifferent to the well-being of an innovator, then IPR will not be enforced even if the innovator wishes to incur the monitoring costs (in which case enforcement is costless for the government). An absence of enforcement also maximizes the production of the GM crop, so zero enforcement will also be the optimal choice of a government wishing to maximize the adoption of the new technology.

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[1] Implicit in this analysis is the assumption that the agronomic characteristics and production potential of GM seed purchased from the innovating firm are identical to those used illegally; that is, the GM seed bought from the black market and that saved by the farmer are perfect substitutes for GM seed purchased from the innovator.

Alternatively, enforcement of IPR will be perfect when the domestic government highly values the economic benefits accruing to innovators or when the innovating firm has control over both audits and the magnitude of the fines on proven IPR violators. While it is possible for the innovating firm to investigate the violation by agricultural producers, it is not very likely that a domestic government will delegate domestic producers' punishment to a foreign firm. Although innovators can (and do) lobby for increased protection of their intellectual property, the domestic government remains responsible for establishing fines for IPR infringement. Thus, even when the innovator monitors the compliance of farmers, the domestic government effectively determines the level of IPR enforcement.

Since the level of IPR protection in the developing country is determined by the political preferences of the domestic government, the question that naturally arises is, what are the determinants of the weight being placed by the government on innovator rents? Factors affecting the importance that domestic governments place on innovator rents include:

- the political influence of the innovating firm in the developing country;
- the bilateral relationship with, and the fear of retaliation from, the country of origin of the innovating firm;
- the severity of the sanctions in cases where developing countries are successfully convicted for imperfectly enforcing the innovator's IPR;
- the conjecture of domestic governments regarding the effects of their enforcement policy on the future development of and domestic access to new technologies; and
- the size of the enforcement costs.

The innovator's political influence or the strength of the relationship between the developing country and the country of origin of the innovating firm will directly affect

- the successful detection and conviction of imperfect IPR enforcement;
- the degree of severity of potential retaliatory sanctions;
- the strength of the government's belief that extensive violation of IPR will adversely affect the future development of new technologies (and domestic producer access to them); and ultimately
- the level of IPR protection in the developing country.

Similarly, these factors will inversely affect the costs associated with IPR enforcement in the developing country.

Enforcement of IPRs and Differential Pricing of the New Technology

Different governments can be expected to have different attitudes toward innovator rents and thus different enforcement policies. Because the extent of IPR infringement affects the price of the new technology, differences in the level of IPR protection provide an alternative justification for (and explanation of) differential pricing of the new technology in different countries around the world—a strategy adopted by leading innovators in the sector.

Consequently, IPR infringement increases the competitiveness of domestic producers who use the new technology by placing foreign producers who comply with the provisions of an innovator's IPRs at a cost disadvantage. The greater the extent of the IPR violation, the lower the price of the new technology and the greater the cost advantage of domestic producers relative to producers in countries where IPRs are more effectively enforced. Thus lax IPR enforcement can be used strategically by governments intent on increasing the competitiveness of their producers in international markets.

Infringement of IPRs and the TRIPs Agreement

Given the absence of an effective supranational monitoring agency and the lack of an agreement on the penalties associated with violating IPRs, the benefits from IPR infringement rationalize the lax enforcement and widespread violation of IPRs in developing countries. In terms of the TRIPs Agreement, it seems well understood that the outcome of the ongoing negotiations on the magnitude of fines for IPR infringement will be critical for the future level of

protection enjoyed by innovators or holders of IPRs. What needs to be equally well understood, however, is that for IPRs to be effectively enforced the TRIPs agreement must go beyond the norms of GATT.

If the penalties determined under TRIPs follow the customary retaliatory sanctions under GATT—simply offsetting the value of losses incurred by innovators—they will prove an insufficient incentive in protecting IPR because the gains from lax enforcement of IPR by a developing country exceed the losses incurred by innovators. Unless the WTO manages to "exceed its usual retaliatory limits" and establish an effective enforcement mechanism for implementing TRIPs, enforcement of IPR will remain imperfect and innovators' abilities to obtain value for their biotech traits will likewise be limited. Given the lack of precedents and the opposition among many developing countries (and their various advocates) to IPRs, reaching an agreement on the establishment of fines that would exceed innovator damages will not be easy.

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RESEARCH AT A GLANCE

Biotechnology and Genetic Resource Policies

Brief 6, January 2003

Conserving Genetic Resources for Agriculture: Counting the Cost

Bonwoo Koo, Philip G. Pardey, and Brian D. Wright

As improved crop varieties developed by scientific breeding spread throughout the world in the latter half of the 20th century, the risk of excessive reliance by farmers and breeders on a narrowing genetic base was dramatized by the infestation and vulnerability of U.S. hybrid corn with cytoplasm male sterility to southern corn leaf blight. Events like this spurred worldwide efforts to greatly expand the amount of agricultural biodiversity conserved in genebanks. More recently, microarray and other modern biotechnologies that provide new and less costly ways of screening crop samples for useful traits have increased the value of conserved genetic resources and focused worldwide attention on access to and use rights of traditional crop varieties, or landraces, stored *in situ* (place of origin) or in *ex situ* genebanks worldwide.

The 11 genebanks maintained by the research centers of the Consultative Group on International Agricultural Research (CGIAR) conserve more than 666,000 accessions (plant or seed samples) of crops grown mainly by poor people, staple food crops grown worldwide, and tree species used in agroforestry systems. This collection constitutes a sizable share—perhaps 30 percent or more—of the unique entries in genebank collections worldwide. Conservation of this valuable germplasm should have a very long-term, if not perpetual, perspective. But funding for this long-term conservation service is currently provided on a precarious, year-by-year basis. This mismatch between the generally short-term nature of the financial support and the long-term nature and intent of the effort could threaten the security and future availability of this genetic material. A plan to judiciously match the duration of the funding commitments to the duration of the conservation commitments was unveiled at the World Food Summit in Rome in June 2002 and further elaborated at the World Summit on Sustainable Development in Johannesburg in August 2002. It involves an effort to tap private and public sources of support to establish a Global Conservation Trust (GCT) fund designed to sustain the long-term conservation and use of agricultural germplasm held in *ex situ* genebanks.

But just how costly is it to conserve genetic resources in genebanks and maintain their viability and sample sizes in perpetuity? In this brief we estimate the costs of conserving specific crop species in *ex situ* genebanks in perpetuity, including the costs of maintaining healthy and viable seeds and other plant breeding material (collectively called "germplasm") stored in the field or in vitro. We also show how these estimates change in response to variations among crops, conservation protocols, and institutional arrangements. The present value of these in-perpetuity costs indicates the necessary size of an endowment or trust fund that would furnish an income stream sufficient to underwrite long-term conservation efforts, thus keeping this valuable resource available for use in maintaining biodiversity and supporting plant breeding for the foreseeable future.

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The CGIAR Genebanks and Their Conservation Services

Since the 1970s the 11 genebanks now maintained by the CGIAR at its international crop-breeding centers have become a pivotal part of a global conservation effort. In 2001 the CGIAR genebanks held about 666,000 germplasm accessions of crops, forages, and agroforestry trees (Table 1). As the world repository of germplasm for the poor, CGIAR genebanks hold predominantly landraces and wild varieties of crops (73 percent of the total) that are especially important to people in developing countries, such as cassava, yam, and chickpea, and crops grown worldwide, such as rice, wheat, and maize. As the amount of material held in genebanks worldwide grew markedly in the past few

Table 1—CGIAR germplasm holding and distributions

Center/location	Crop	Total number of accessions, 2001	Average annual dissemination, 1995-99
CIAT, Colombia	Cassava	8,060	344
	Common bean	31,400	910
	Forages	24,184	8,969
	Total	63,644	10,223
CIMMYT, Mexico	Wheat	154,912	3,503
	Maize	25,086	8,177
	Total	179,998	11,680
CIP, Peru	Potato	7,639	4,330
	Sweet Potato	7,659	1,970
	Andean roots/tubers	1,495	6
	Total	16,793	6,306
ICARDA, Syria	Cereal	60,013	10,907
	Forages	30,528	8,576
	Chickpea	11,219	5,200
	Lentil	9,962	3,804
	Faba bean	10,745	2,530
	Total	122,467	31,017
ICRAF, Kenya	Agroforestry trees	10,025	n.a.
ICRISAT, India	Sorghum	36,721	4,272
	Pearl millet	21,392	2,077
	Pigeon pea	13,544	1,729
	Chickpea	17,250	5,951
	Groundnut	15,342	4,009
	Minor millets	9,252	316
	Total	113,501	18,355
IITA, Nigeria	Bambara groundnut	2,029	52
	Cassava	3,529	913
	Cowpea	16,001	2,766
	Yam	3,700	258
	Others	5,537	520
	Total	30,796	4,509
ILRI, Kenya	Forages	13,204	2,038
IPGRI/INIBAP, Italy	Musa	1,143	78
IRRI, Philippines	Rice	99,132	9,017
WARDA, Côte d'Ivoire	Rice	15,377	842
CGIAR total		666,080	94,065

Source: Authors' survey and unpublished data provided by CGIAR centers.

Note: n.a. indicates not available.

decades, the number of duplicates proliferated. With only 1 to 2 million of the estimated 6 million accessions held worldwide deemed unique (FAO 1998), the high proportion of landraces and wild varieties in the CGIAR collection means its share of the world's unique ex situ accessions could be much higher—perhaps 30 percent or more—than its share of the global ex situ collection.

For our costing analysis, in consultation with genebank curators and breeders, we grouped typical genebank operations into three main services. Genebank services include conserving agricultural genetic diversity in the form of a base collection held in controlled environment conditions to maintain the stored plants (or plant parts) and seeds for use in the distant future. Environmental conditions are typically 15 to 20 percent relative humidity and -18 to -20°C for seeds, or 23°C and 1,500 to 2,000 lux for vegetatively propagated material like yams and cassava held in culture mediums. Germplasm must be placed in long-term storage that is viable and disease-free; the viability of the stored material must be periodically tested, and, when indicated, viability must be restored by regeneration (planting the aged seeds and storing their progeny). For safety reasons, duplicates in the collection are periodically sent to other locations for storage.

To make accessions available upon request for current use, an active collection of germplasm is maintained in a medium-term storage facility from which samples of seed are available for dissemination to researchers, crop breeders, farmers, and other genebanks. From 1995 to 1999, the CGIAR centers shipped about 94,000 samples per year (Table 1). This material is an important source of genetic diversity and a potentially valuable source of novel and useful traits. Current use of this type of material is lower than for well-characterized and better-known breeding lines held by breeders, however, because promising traits are more difficult to identify and take time and effort to introduce into new cultivated varieties ("cultivars") distributed to farmers.

Active collections typically require more frequent regeneration than material held in base collections because the environment in medium-term storage facilities is not as conducive to germplasm longevity and germplasm samples eventually require replenishment. Most, but not all, seed samples will remain viable for 20 to 30 years in medium-term storage depending on the species, the initial seed quality, and the specifics of the storage environment.

Genebanks must maintain basic databases to indicate the source of the seed samples and their physical attributes. To facilitate the use of material for crop improvement or other research purposes, genebanks screen the collection for accessions with resistance to certain pests and diseases. Phenotypic information becomes increasingly valuable when coupled with the use of modern biotechnologies to identify the genetic basis for certain traits, along with other genetic information deemed desirable in breeding programs.

The Costs of Conservation Services in Perpetuity

The costs of some operations, such as storage, accrue annually, whereas the costs of other operations are incurred periodically—for example, every 5 years or so for the viability testing of samples and every 20 to 30 years for regeneration. Thus the conservation costs of a sample in any particular year depend on the time in storage and the status of the sample. Figure 1 illustrates the profile of conservation costs incurred during the life cycle of an accession from introduction, expressed in present-value terms with a positive discount rate. When an accession is newly introduced into a genebank at time zero, it is typically regenerated and tested for viability and health, and the costs incurred in that year are especially high. During a normal year when an accession is simply held in storage (such as time t_A in Figure 1), the conservation cost consists of only the long-term costs of storage. When an accession requires regeneration after failing a viability test, the costs in that year (time t_B in Figure 1) are higher than the cost at time t_A. Year t_C represents a year in which a sample successfully passes a viability test and requires no regeneration. The present value of conserving an accession in perpetuity is obtained by summing all the areas (irrespective of their shading) of the bar graph in Figure 1.

Conservation costs depend critically on (1) the type of crop being conserved, (2) institutional differences such as cost-sharing opportunities with other local activities, and (3) the local climate and the general state of the infrastructure (such as electricity supplies, communications, and international shipment options) available to each genebank. For example, regenerating cross-pollinating crops or wild and weedy species is typically more complicated than regenerat-

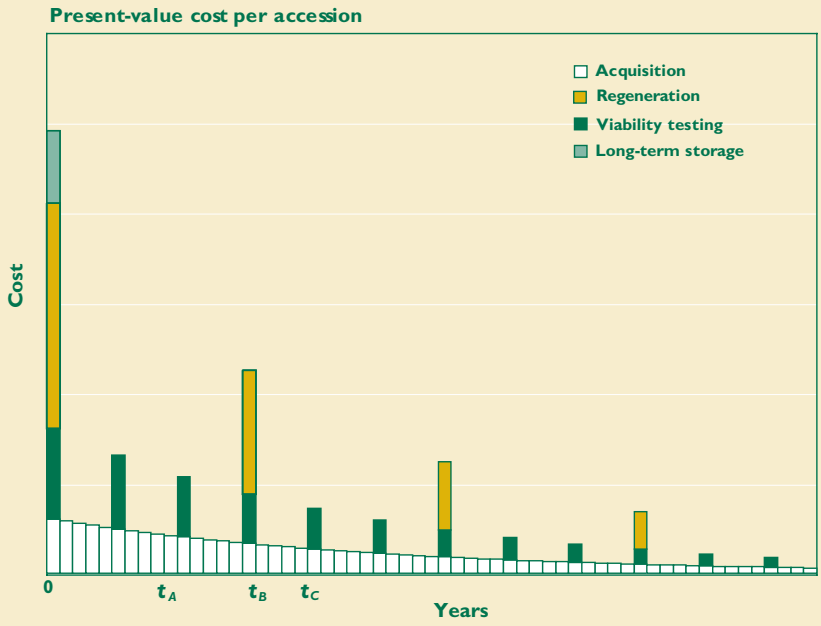
ing self-pollinating cultivated species. Vegetatively propagated species maintained in vitro as clones or in field genebanks are much more expensive to conserve than stored seeds. The local wage structure and the composition of the labor force (which are affected by a location's state of development and local labor laws and practices) also are important. Moreover, if the local climate is inappropriate for regeneration of some accessions, additional costs may be incurred by regeneration at other locations.

Our approach was to estimate a representative set of baseline costs per accession in ways that would make it possible to evaluate the sensitivity of these baseline costs to differences in key crop-, location- and institution-specific factors. To address these diverse factors systematically within a reasonable timeframe, we conducted on-site cost studies of five CGIAR centers over several years, in close collaboration with center personnel, standardizing our treatment of the data as much as possible. The five centers, with the study dates, are the International Maize and Wheat Improvement Center (CIMMYT, 1998), the International Center for Tropical Agriculture (CIAT, 2000), the International Center for Agricultural Research in the Dry Areas (ICARDA, 1998), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT, 1999), and the International Rice Research Institute (IRRI, 1999). The holdings of these five centers comprise nearly 90 percent of the total CGIAR-held accessions. To adjust for the effects of inflation, we expressed all costs in year 2000 prices using a weighted average of the producer price index for the G7 (highly-developed) countries constructed by the authors.

We found that simply holding a seed sample for one year (in which the sample requires no special treatment) costs less than US$1.50 per accession per year for most crops, except for maize, which costs US$2.16 per accession, and cassava conserved in vitro, which costs US$11.98 per accession. These storage costs consist mainly of the costs of electricity and the annualized capital cost of the storage facility, with a small expense for maintaining the storage equipment. The storage costs of crops at IRRI and ICARDA (US$0.47 per accession for crops kept at both locations) are comparatively low because of cheap labor and electricity costs, whereas costs are higher at ICRISAT (US$1.32 per accession) where electricity is expensive. The comparatively high cost of storing maize results from its comparatively large seed size (less seed fits in a given storage space and more costly containers are required).

Calculating the present value of conservation costs in perpetuity (including periodic viability testing and regeneration costs) changes the ranking. The costs of forage crops conserved at CIAT (US$89.35 per accession with regeneration) and of wild rice at IRRI (US$68.76 per accession) are now higher than those of chickpeas or sorghum at ICRISAT (US$15.48 and US$14.66 per accession, respectively) because of the higher costs of repeated regeneration of forages and wild rice. As a rule, wild and weedy varieties and cross-pollinating crops that are relatively expensive to regenerate are more costly to conserve over the long term. Conserving vegetatively propagated crops (such as cassava at CIAT at US$25.05 per accession) is also comparatively costly owing to the intensity of labor required for fre-

FIGURE 1 Profile of the present value of the conservation cost stream



quent subculturing of in vitro accessions or for annual replanting of field genebanks.

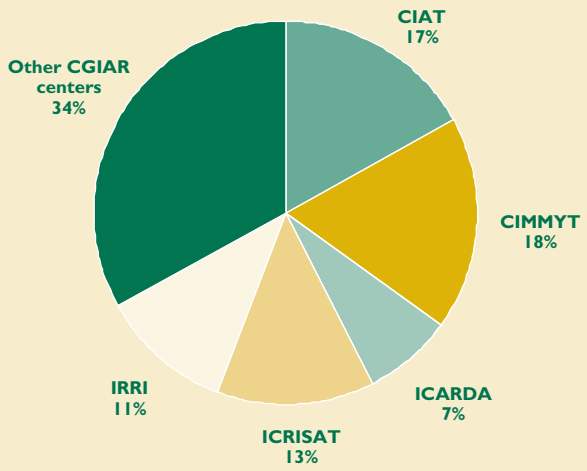
Our best baseline estimates of the present value of these in-perpetuity costs show that a US$149 million endowment invested at a real (net of inflation) rate of interest of 4 percent per year would generate a real annual revenue flow of US$5.7 million, sufficient to cover the costs of conserving and distributing the current holdings of all 11 CGIAR genebanks in perpetuity. About 20 percent of the endowment funds (nearly US$30 million) would be needed to underwrite the ongoing purchases of equipment and genebank buildings as they are replaced. The rest would need to be set aside to meet the recurring noncapital costs.

The conservation and distribution activities undertaken by the five centers we studied (which collectively conserve 87 percent of the CGIAR's current germplasm holdings) could be supported with 66 percent of the total endowment fund, with the remaining 34 percent underwriting activities at the six centers we did not study directly (Figure 2). These estimates show that 13 percent of the genebank holdings account for 34 percent of the total costs. This is because the vegetatively propagated material that constitutes a large part of collections of the International Institute of Tropical Agriculture (IITA), the International Potato Center (CIP), and the International Network for the Improvement of Banana and Plantain (INIBAP) and the tree species conserved by International Centre for Research in Agroforestry (ICRAF) are intrinsically costly to store and regenerate. CIAT and CIMMYT constitute 17 and 18 percent, respectively, of the total costs. Wage rates in Colombia and Mexico are comparatively high by developing-country standards, and major shares of the accessions at these genebanks are crops that are intrinsically costly to conserve—specifically, vegetatively propagated cassava at CIAT and cross-pollinating maize at CIMMYT.

A sensitivity analysis reveals that if the interest rate is higher (6 percent) and if accessions remain viable much longer (a possibility with modern technologies), making the cycles of regeneration and viability testing less frequent, the size of the necessary endowment falls to US$100 million. Conversely, if the interest rate is 2 percent and viability testing and regeneration are more frequent, the required endowment is US$325 million.

Our cost estimates include only those core activities required to conserve and distribute the CGIAR holdings now and forever. The general lack of evaluation information on stored germplasm has severely limited its use in crop breeding and thereby curtails the demand for genebank material (Wright 1997). Modern molecular biology techniques could be used to tap the "wide repertoire of genetic variants created and selected by nature over hundreds of millions of years [that are] contained in our germplasm banks in the form of exotic accessions" (Tanksley and McCouch 1997, 1006). Determining the cost of the characterization activities that provide the molecular basis for modern breeding efforts and thereby greatly enhance conventional crop-breeding techniques is a tricky exercise, depending in part on the state and nature of the rapidly changing biotechnologies and on the optimal timing of their use (Koo and Wright 2000). In the absence of further detailed study, we believe it prudent to match the resources devoted to conservation purposes (estimated here) with a comparable sum for their characterization and evaluation. This step will greatly enhance the contribution of the conservation effort to the crop-breeding efforts of future generations worldwide.

FIGURE 2 Share of total CGIAR conservation costs, by center



Total = $144.7 million

Source: Koo, Pardey, and Wright (2002).

The Benefits of a Long-Term Commitment to Germplasm Conservation

These conservation costs need to be set against the tens of billions of dollars of benefits for developing-country producers (through increased productivity and lower costs of production) and consumers (through lower food prices and improved grain quality) that breeding efforts drawing on germplasm conserved in the CGIAR centers and elsewhere have brought about in the past several decades (Alston et al. 2000). There is no reason to think the importance of diverse germplasm in ensuring increased food production will diminish any time soon: with little land left to bring into agriculture and a projected 3 billion increase in world population by 2050 (almost all occurring in poorer countries), yields must continue to be increased. This study provides a firm empirical basis for ensuring in perpetuity the financial viability of the conservation efforts of the CGIAR centers. Setting aside US$200–300 million to underwrite the CGIAR's genebank conservation, characterization, evaluation and distribution efforts into the very distant future is a small down payment compared with the billions of dollars of benefits that will be generated by continued access to and use of this germplasm.

For a more detailed version of this summary, see Koo, Pardey, and Wright, 2002. http://sgrp.cgiar.org/SGRP-IFPRI.pdf

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