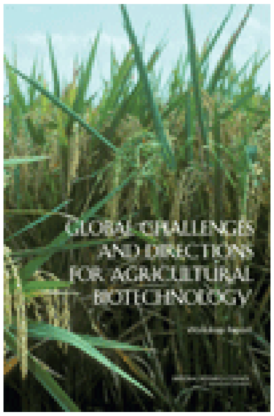

Global Challenges and Directions for Agricultural Biotechnology: Workshop Report

Sterring Committee on Global Challenges and Directions for Agricultural Biotechnology: Mapping the Course, National Research Council

ISBN: 0-309-12078-0, 74 pages, 6 x 9, (2008)

GLOBAL CHALLENGES AND DIRECTIONS FOR AGRICULTURAL BIOTECHNOLOGY

Workshop Report

Steering Committee on Global Challenges and Directions for Agricultural Biotechnology: Mapping the Course

Board on Agriculture and Natural Resources

Board on Life Sciences

Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, N.W. Washington, DC 20001

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This workshop was supported by the U.S. Department of State Award No. S-LMAQM-03-M-4207 and the National Academies. Any opinions, findings, and conclusions or recommendations in this document are those of the authors and do not necessarily reflect the views of the organizations or agencies that provided support for the project. Mention of trade names, commercial products, or organizations does not constitute their endorsement by the sponsoring agency.

International Standard Book Number-13: 978-0-309-12077-7
International Standard Book Number-10: 0-309-12077-2

Additional copies of this report are available from the National Academies Press, 500 Fifth Street, NW, Lockbox 285, Washington, DC 20055; (800) 624-6242 or (202) 334-3313 (in the Washington metropolitan area); Internet, http://www.nap.edu.

Printed in the United States of America.

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

www.national-academies.org

STEERING COMMITTEE ON GLOBAL CHALLENGES AND DIRECTIONS FOR AGRICULTURAL BIOTECHNOLOGY: MAPPING THE COURSE

CALESTOUS JUMA, *Chair*, Harvard University, Cambridge, Massachusetts
DEVIN M. BARTLEY (through May 2004), United Nations Food and Agricultural Organization
EDWARD GROTH III, Groth Consulting Services, Pelham, New York
RICHARD R. HARWOOD, Michigan State University, East Lansing
LUIS HERRERA-ESTRELLA, National Polytechnic Institute Irapuato, Guanajuato, Mexico
RICHARD A. JEFFERSON (through August 2004), Center for the Application of Molecular Biology to International Agriculture
PETER M. KAREIVA (through October 2004)**,** The Nature Conservancy, Seattle, Washington
BARBARA A. SCHAAL, Washington University, St. Louis, Missouri
BARBARA O. SCHNEEMAN (through July 2004), U.S. Food and Drug Administration, College Park, Maryland
JENNIFER THOMSON (through April 2005)**,** University of Cape Town, South Africa
GREG TRAXLER, Auburn University, Alabama
JOSE A. ZAGLUL, Earth University, San José, Costa Rica

Project Staff

ROBIN SCHOEN, Study Director
PEGGY TSAI, Associate Program Officer
KAREN L. IMHOF, Administrative Assistant
KIM WADDELL, Study Director (through May 2004)
CHARLOTTE KIRK BAER, Study Director (May–October 2004)
MICHAEL KISIELEWSKI, Research Associate (through May 2004)
NORMAN GROSSBLATT, Senior Editor

BOARD ON AGRICULTURE AND NATURAL RESOURCES

W. REG GOMES, *Chair,* University of California (*Emeritus*), Oakland
ROGER N. BEACHY, Donald Danforth Plant Science Center, St. Louis, Missouri
H.H. CHENG, University of Minnesota (*Emeritus*), St. Paul
DANIEL M. DOOLEY, University of California, Oakland
JOAN H. EISEMANN, North Carolina State University, Raleigh
KIRK C. KLASING, University of California, Davis
VICTOR L. LECHTENBERG, Purdue University, West Lafayette, Indiana
ROBERT PAARLBERG, Wellesley College, Watertown, Massachusetts
KEITH PITTS, Curragh Oaks Consulting, Fair Oaks, California
HAL SALWASSER, Oregon State University, Corvallis
PEDRO A. SANCHEZ, The Earth Institute at Columbia University, Palisades, New York
NORMAN R. SCOTT, Cornell University, Ithaca, New York

Staff

ROBIN SCHOEN, Director
KAREN L. IMHOF, Administrative Assistant
EVONNE TANG, Senior Program Officer
AUSTIN J. LEWIS, Program Officer
CAMILLA YANDOC ABLES, Associate Program Officer
PEGGY TSAI, Associate Program Officer
JANET MULLIGAN, Research Associate
RUTH S. ARIETI, Senior Program Assistant

Preface

The advent of agricultural biotechnology was marked by a wide array of debates inspired by concerns about safety. Those concerns were shaped by public perceptions that tended to emphasize the risks associated with agricultural biotechnology. Although the concerns were justified and had to be taken seriously, they tended to downplay the potential benefits of the technology. Moreover, much of the debate about agricultural biotechnology was shaped by advocacy efforts aimed at particular policy objectives.

This committee was charged with framing the biotechnology debate in terms of problem solving. Its focus was to identify important current and emerging global problems and then explore the possible application of biotechnology as one of many approaches to ease the problems, recognizing that all new technologies carry scientific and socioeconomic risks.

However, failing to use the technologies where they show potential benefit also may be a risky strategy. Thus, the committee felt that the scientific risks and socioeconomic issues associated with biotechnology need to be examined in the context of technology's role in addressing long-term goals, such as preserving biodiversity, conserving natural resources, achieving food security, improving the health of populations, cleaning up polluted lands and bodies of water, and obtaining adequate sources of energy.

That approach will continue to be relevant in light of uncertainties associated with global efforts to respond to challenges arising from global change. Agricultural biotechnology embodies a set of generic tools that offer options for addressing persistent and emerging economic, social, and ecological problems. Failing to explore the potential value of such technologies suggests that doing nothing is safer than trying new technologies, an assumption that may be as misleading as the exuberance with which the benefits of new applications are sometimes described.

In the interest of open-mindedness and knowledge-based approaches to decision making, it is the hope of the committee that this workshop report reflects an effort to balance concerns about the risks that attend new technologies with the seriousness of the problems we face. The potential value of such technologies is great, and as technologies continue to advance, the issues raised at the workshop will remain in the forefront for some time to come. We hope that this workshop report will serve as a source of inspiration for more detailed explorations of technologies that can then serve to address global challenges.

Calestous Juma, *Chair*
Steering Committee on Global Challenges and Directions for Agricultural Biotechnology: Mapping the Course

Acknowledgments

This report is a product of the cooperation and contributions of many people. The committee would like to thank all the speakers and participants who attended the workshop on October 25-26, 2004. Their presentations helped to set the stage for the fruitful discussions in the sessions that followed. Harrison Wein prepared an initial summary of the workshop, which was useful to the committee in writing this report.

This workshop report has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of the independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following for their review of this report:

Anthony J. Cavalieri, U.S. Agency for International Development
Robert J. Frederick, U.S. Environmental Protection Agency
Jean Halloran, Consumers Union
Tilahun D. Yilma, University of California, Davis

Although the reviewers listed above have provided constructive comments and suggestions, they were not asked to endorse the workshop report nor did they see the final draft of the report before its release. The review of this report was overseen by Dr. Charles J. Arntzen, Arizona State University. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the author committee and the institution.

Contents

SUMMARY 1

1 INTRODUCTION 5
Workshop Organization, 6
Organization of the Report, 8

2 OPPORTUNITIES FOR APPLYING BIOTECHNOLOGY 9
Improving Crop Productivity, 10
Improving the Nutritional Value of Crops, 14
Improving Food Security, 15
Protecting and Preserving Biodiversity, 17
Enhancing Natural Resource Conservation, 19

3 CHALLENGES AND FUTURE CONSIDERATIONS IN REALIZING THE GLOBAL POTENTIAL OF AGRICULTURAL BIOTECHNOLOGY 21
Challenge 1: Developing Appropriate and Affordable Technologies, 22
Challenge 2: Determining Priorities for Biotechnology, 25
Challenge 3: Engaging the Citizenry, 27
Challenge 4: Building Scientific and Local Capacity, 31
Challenge 5: Developing Sustainable Partnerships, 33
Challenge 6: Engaging in Global Dialogue on Agreements and Protocols, 35

Challenge 7: Anticipating Future Needs and Directions, 43
Closing Thoughts, 45

REFERENCES 47

APPENDIXES

A Steering Committee Biosketches 51
B Workshop Agenda 55
C List of Workshop Participants 59

BOXES

1-1 Statement of Task, 7

2-1 Selected Opportunities for Applying Biotechnology, 11
2-2 Some Tools of Biotechnology (Apart from Genetic Engineering), 12

3-1 The Most Promising African Farming Systems for Increasing Food Security, 23
3-2 International Agreements on Biodiversity and Biosafety, 36
3-3 The Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), 40
3-4 Organizations that Promote Access to Research and Transfer Technology, 44

Summary

Many developing countries are exploring whether biotechnology has a role in addressing national issues such as food security and environmental remediation, and are considering whether the putative benefits of the technology—for example, enabling greater agricultural productivity and stability in the food supply—outweigh concerns that the technology might pose a danger—to biodiversity, health, and local jobs. Some policy leaders worry that their governments are not prepared to take control of this evolving technology and that introducing it into society would be a risky act. Others have suggested that taking no action carries more risk, given the dire need to produce more food.

The questions swirling around the potential applications of biotechnology and what developing countries might consider as they contemplate adopting biotechnology was the subject of an international workshop, Global Challenges and Directions for Agricultural Biotechnology: Mapping the Course, organized by the National Research Council on October 24-25, 2004, in Washington, DC. The workshop was attended by 75 stakeholders from developing and industrialized countries. The ideas of participants from developing countries formed the cornerstone of the agenda and topics for discussion.

Presenters at the workshop described applications of biotechnology that are already proving their utility in both developing and developed countries. These include genetically engineered (GE) crops that produce the *Bt* insecticide, are resistant to herbicide for use in no-till farming systems to simplify weed control, and GE plants that metabolize toxic chemicals to remediate contaminated soils and water. In addition to GE products, the use of biotechnology as an important tool for discovering valuable traits (for example, better nutrient composition) in the natural biodiversity of food plants was also highlighted, along with the ability to reconstruct or find "lost" germplasm for conservation. Future innovations developed with biotechnology were envisioned—from drought-resistant crops and high-performing biofuels, to plant-based vaccines and food crops with a long storage life.

All of the ideas described at the meeting were attractive in different ways, but the question on the minds of the workshop participants from developing countries was not *what* biotechnology could do so much as *who* would be in control of the decision to develop or adopt biotechnology applications. There is a perception that by approving the use of GE seeds and products, developing countries will be at the mercy of companies that will alter accepted farming practices, obligate farmers to purchase high-cost inputs, disrupt local traditions, damage the environment, and reduce employment. And yet, the potential for biotechnology to improve agriculture and address other societal needs appears to be compelling enough that the leaders of developing countries are not able to ignore the possibility of adopting it.

As the workshop discussions unfolded, it seemed to the participants that the policy-makers in developing countries are faced with several interdependent challenges that will have to be addressed simultaneously if those countries are to realize the full benefits of biotechnology. For example, many major crops grown in the developing world and the limitations of those crops are different from those that have been the focus of genetic engineering efforts in the industrialized world, so **shifting the focus of biotechnology to meet the specific agricultural needs of developing country farmers** would be a first step.

Identifying the particular applications of biotechnology that should have the highest priority for development and implementation in a developing country could be facilitated by a **transparent and open decision-making process** that involves farmers, scientists, and other stakeholders. Devising such a process might not be simple, could differ from country to country, and will take time to implement. Different modes of communication to reach the diversity of stakeholders, including small farmers and rural communities in remote areas, are likely to require some creativity, and will not always work perfectly, as lessons in industrialized countries reveal. Nevertheless, one objective of the decision-making process is to ensure that the "right" decisions are being made, meaning that it is important for the process to help define criteria for **prioritizing biotechnology applications** (especially given scarce resources and competing societal priorities) and that specific requirements of the application make the most sense for the farmer or consumer. The participation of stakeholder groups helps to ensure that the technologies pursued are those that are most **appropriate and affordable**, and will generate a return on research and development investment.

The second goal of having such a process is to build confidence among citizens and stakeholders, so they can feel that decisions have been made in an open manner with the benefit of relevant input. Moreover, when that process includes a scientifically-based biosafety review, the benefits and risks of the technology can be publicly aired, and the citizens will have **greater confidence in the safety** of the proposed technology for human health and the environment.

One of the most effective decisions that developing countries can make to take control of and capture the benefits of biotechnology is to **build national and local scientific expertise and capacity**. When that capacity exists, a source of independent scientific advice is available to decision-makers and to national negotiators involved in international discussions on trade, biotechnology, intellectual property rights, and other issues. National scientific expertise and capacity are necessary for a robust and independent evaluation of the biosafety of novel GE products proposed to be introduced. Last, but not least, that expertise and capacity would be the basis of a research and extension enterprise that could lead to locally-generated biotechnology innovations and applications developed with the input of local users.

No one at the workshop had any illusions that the poorest of countries could build the scientific capacity they need without help. Because national resources are always limited, finding **partners in the for-profit private sector, in neighboring and regional research institutes, and in nonprofit foundations** would help developing countries take ownership of biotechnology applications. Such partnerships succeed when there is a clear understanding of the roles of each respective partner, so that the benefits that come from the partnership are shared by all parties.

Finally, the future holds many unknowns. Climate change and population growth will affect the supply and demand for food and the ability of the environment to support the economic activities of society. The nations of the world need to respond to these changes in the context of constantly evolving technological capabilities by negotiating on many different issues that will affect developing countries. This includes issues related to the ownership and use of biotechnology. Scientists, lawyers, and political leaders in developing countries are compelled to be stewards of the use of biotechnology in meeting national needs. The time is now to strengthen those nations' ability to be active participants in international forums on the future of this important technology.

1

Introduction

Many developing countries are evaluating how they might benefit from advances in biotechnology and are asking whether biotechnology can play a role in addressing problems of food security and poverty. In developing countries, some of greatest pressures for biotechnology adoption come from within their scientific communities and from their local businesses. There is considerable hesitation in governmental deliberations because introducing and investing in these advances requires, at a minimum, a commitment of precious financial and administrative resources, whereas the anticipated payoff from that investment—greater agricultural production, cleaner water, healthier food, and increased farmer income—is uncertain. With relatively weak economic, social, and physical infrastructures, some developing countries question whether the technology is appropriate and can be successful in benefiting their society. Moreover, although many countries have embraced the agricultural applications of biotechnology, some have rejected them, particularly in Europe. Developing nations—with few sources of internal, independent scientific and policy advice—are trying to sort out for themselves whether biotechnology is a sensible option to address their needs.

There is frequent attention paid to national and international debates about whether the use of biotechnology brings greater benefits than risks to society, but less exposure is given to the issues that developing countries struggle with in adopting biotechnology. Because there is a scarcity of neutral forums that are not associated with any particular government agency or stakeholder group, the National Research Council (NRC) decided to convene a workshop of persons familiar with that struggle and with the complexity of issues surrounding agriculture and rural economic development in some of the world's poorest nations. The purpose of the workshop was twofold: to illustrate the needs of developing countries and the *potential* of biotechnology to address them, and to voice concerns about what adopting biotechnology would mean—on multiple levels and for a diverse set of actors—that will affect and be affected by biotechnology.

WORKSHOP ORGANIZATION

The workshop was a cooperative effort of the NRC's Board on Agriculture and Natural Resources and Board on Life Sciences and was organized under the auspices of the Committee on Agricultural Biotechnology, Health, and the Environment, a joint standing committee of the two boards. These units developed a proposal, scope, and statement of task (Box 1-1) for the workshop and obtained funding for it from the National Academy of Sciences and the U.S. Department of State.

The NRC appointed a small steering committee to develop the meeting agenda and to identify and invite participants. Members of the steering committee, whose biographies can be found in Appendix A of this report, included persons with ties to developing countries and with experience in their agronomic and socioeconomic conditions. The membership reflected an array of views about the utility and potential of agricultural biotechnology for addressing problems of developing countries. However, the committee agreed that the opportunity cost of not using biotechnology is significant for human nutrition and health, and this cost affects not only the developing world, but human populations in general. That underlying thought became the impetus for the workshop.

To prepare for the workshop, the committee created an electronic forum to reach stakeholders and experts in and outside the United States, particularly those living in or involved with agriculture in developing countries. They were asked to identify important global challenges that might be addressed with biotechnology and were instructed not to limit their answers to existing applications but to consider the problems for which biotechnology applications should be developed in the future. Suggestions were made by people in a variety of constituencies in developing countries, including government, academe, nongovernment organizations, and the private sector.

On the basis of the ideas submitted, the steering committee identified four major categories of potential opportunity relevant to biotechnology: increasing agricultural productivity, improving food security and human nutrition, protecting biodiversity and enhancing conservation, and designing innovation systems that would allow developing coun-

Box 1-1
Statement of Task

An ad hoc steering committee will plan and host a workshop to first identify important global problems and then discuss the possible use of agricultural biotechnology as one of many tools for easing these problems. Focusing on challenges that society faces now or will face in the future, experts will be brought together with biotechnologists, other scientists, and stakeholders to address the following questions:

(1) what are the most important global problems facing society (focusing on the long-term goals of preserving biodiversity, conserving natural resources, achieving food security, improving the health of populations, cleaning up polluted lands and bodies of water, and obtaining adequate sources of energy),
(2) can the use of agricultural biotechnology, as one of many tools, help provide solutions to these problems, and if so,
(3) what are the scientific risks and socioeconomic issues associated with its use that need to be considered.

Opinions and ideas from people in developing countries will form the cornerstone of the workshop agenda. Several months prior to the workshop, an electronic forum will be used as one of several mechanisms to reach stakeholders and experts who would not typically have direct input into National Academies activities, particularly those close to agriculture in developing countries.

Diverse applications of agricultural biotechnology involving transgenic plants, terrestrial and aquatic animals, insects, and microorganisms will be considered. Primary goals of the workshop are to identify policy issues and to explore research and directions for the safe use of agricultural biotechnology in addressing current and future global problems.

tries to be active participants in the new technologies. The agenda for the workshop (Appendix B) was organized around those four themes.

The workshop, which the steering committee titled “Global Challenges for Guiding and Managing Agricultural Biotechnology,” was held in Washington, DC, on October 25-26, 2004, and attended by 75 people who represented developing and industrialized countries’ agricultural agencies, nonprofit organizations, private foundations, universities, and companies involved in agricultural development or biotechnology research (Appendix C).

Speakers and panelists, many of whom were from developing countries, were asked to address the four categories and explore several cross-cutting challenges related to the adoption of new technologies:

- Scientific capacity to implement and develop new technologies.
- Democratic participation in identifying needs and setting priorities.
- Intellectual property issues related to biotechnology.
- Regulatory and trade issues.
- Social and economic capacity to adopt biotechnology innovations.

The discussions emphasized plant biotechnology as a basis for addressing the cross-cutting global challenges because it was not possible to address all types of biotechnology applications; however, it should be noted that these challenges are also relevant to animal, insect, and microbial biotechnology. In the end, the cross-cutting challenges, not the specific needs and technological solutions, generated the most discussion at the workshop. The speakers and panelists from developing countries provided rich insight on these cross-cutting issues and voiced concerns held by many in the developing world. As each application of biotechnology was presented, the social scientists, biologists, and other stakeholders gravitated away from the specifics of the technology and toward the social and other implications of selecting and implementing the technology. Presentations from the workshop are available online at http://dels.nas.edu/banr/GlobalChallenges/GCAgenda.doc.

The opinions and ideas of people in developing countries shaped the discussions at the workshop, and the discussions form the basis of this workshop report. This report is not intended to be a comprehensive study of the subject of biotechnology, but rather it hopes to provide readers with a general understanding of what agricultural biotechnology can do and to inform readers of the multifaceted political and socioeconomic challenges that developing countries will face when they consider applying agricultural biotechnology.

ORGANIZATION OF THE REPORT

Workshop speakers and participants were asked to share their knowledge of agricultural biotechnology and to consider the implications of its applications in the context of developing countries. Chapter 2 summarizes the workshop presentations on several specific uses of plant biotechnology in improving crop yields, improving the nutritional value of food to increase food security, conserving biodiversity, and remediating contaminated soils. Chapter 3 captures the wide-ranging discussion of biotechnology as only one of many tools for solving national and regional problem. It explores the challenges that developing countries need to overcome to realize the benefits of agricultural biotechnology.

2

Opportunities for Applying Biotechnology[1]

The world population has increased from 2.5 billion in 1950 to 6.7 billion today and is estimated to reach almost 9.2 billion by 2050 (United Nations, 2007). With that growth comes the challenge of producing enough food to meet the demands of the world's people and an even greater challenge of producing it in a way that conserves the biodiversity and other natural resources on which societies depend. One estimate is that agricultural production will need to increase by 50 percent by 2020 to meet the world's demand for food (Shah and Strong, 1999).

Technological innovation has helped to ease some problems posed by population growth; over the last 50 years, agricultural productivity has doubled worldwide and even tripled in developing economies (Doering et al., 2002). During the 20th century, the Green Revolution drew on the research of conventional plant breeders to develop higher-yielding crops that were successful in increasing the global food supply. However, the new crop varieties introduced in the Green Revolution created dependence on additional farming inputs and created some new environmental problems. Today, with finite acreage of high-quality agricultural land on which to grow food (Tilman et al., 2001), biotechnology has emerged as a

[1]Since the October 2004 workshop, the agricultural biotechnologies cited in the workshop have progressed rapidly, yet the opportunities for their application are still relevant and have yet to be fulfilled. In a forthcoming National Research Council report, *Emerging Technologies to Benefit Farmers in Sub-Saharan Africa and South Asia* (2008), several promising applications of biotechnology are described to address the problems that small-holder farmers encounter in developing countries.

potential tool for overcoming the current limitations on food production.[2] Many have asked whether biotechnology can live up to its promise and whether it will also generate new dependences and problems.

This chapter describes some of the opportunities for using biotechnology in an agricultural and environmental context as discussed by participants in the workshop, and Box 2-1 provides a summary of opportunities for applying biotechnology. Although increasing crop yields by overcoming agronomic and environmental constraints is the most commonly recognized target of biotechnology, there are many other possibilities for developing useful applications, such as improving the sustainability of farming processes, developing more-nutritious foods, improving water quality, and identifying useful genetic material in nature. The workshop consisted of a series of presentations by lead speakers followed by commentary and shorter presentations by panels of experts. The presentations focused on specific ways in which biotechnology could address a problem or constraint, and the discussions examined the needs of the developing world relative to the potential of biotechnology.

IMPROVING CROP PRODUCTIVITY

Biotechnology is the application of scientific and engineering principles to the processing or production of materials by biological agents to provide goods and services (NRC, 2002a). Agricultural biotechnology encompasses a growing list of techniques that range from simple probes to determine whether an individual plant or animal is carrying a specific gene to measurement of the activity of all an organism's genes (its genome) simultaneously. One technique common in agricultural biotechnology is the integration of a gene from one species into the genome of another. This technique is commonly referred to as genetic engineering, and the resulting product is described as transgenic (having a foreign gene). Genetic engineering allows novel characteristics to be introduced into a plant; this could not generally be accomplished with standard breeding techniques.

Although some commercial products of genetic engineering are well known and were the focus of some of the presentations, the power of biotechnology goes far beyond the ability to make transgenic crops. Being able to recognize the characteristics of an individual organism on the basis of its genetic makeup and having the power to mimic the biological

[2]By 2007, a total of 23 countries were growing transgenic crops. In order of acreage, they include the United States, Argentina, Brazil, Canada, India, China, Paraguay, South Africa, Uruguay, Philippines, Australia, Spain, Mexico, Colombia, Chile, France, Honduras, Czech Republic, Portugal, Germany, Slovakia, Romania, and Poland (ISAAA, 2008).

Box 2-1
Selected Opportunities for Applying Biotechnology

Crop Productivity
- Overcoming biotic stresses
  - Insects
  - Weeds
- Overcoming abiotic stresses
  - Soil fertility
  - Heat stress
  - Drought stress
  - Inefficiency of resource use

Nutritional Value of Crops
- Enhancing vitamin concentrations
- Enhancing mineral concentrations
- Enhancing protein content

Plant-Made Pharmaceuticals
- Vaccines
- Protein therapeutics

Improved Food Security
- Reducing post-harvest loss
- Reducing risks to food production
- Alternative uses

Biodiversity
- Engineering safeguards to protect existing biodiversity
- Preserving biodiversity

Natural Resource Conservation
- Renewable energy
- Phytoremediation

activity of an organism by using its own cellular and molecular machinery are capabilities that allow us to deepen our understanding of all organisms. That knowledge has led to the development of some practical tools, examples of which were identified by workshop participants and are listed in Box 2-2. Ganesh Kishore, of DuPont Agriculture and Nutrition, provided an overview of some available biotechnologies to improve crop productivity, and the presentation provided context for shaping subsequent discussions.

Box 2-2
Some Tools of Biotechnology (Apart from Genetic Engineering)

- Marker-assisted breeding uses conventional breeding techniques informed by specific genetic sequences, or "markers," that segregate according to particular traits. Markers speed up breeding programs by allowing researchers to determine, early in the life of a progeny, whether the traits they hoped to combine from two organisms are present simply by checking for the presence of the markers.

- Tissue culture is used in clonal propagation of plants for which sexual breeding has proved inefficient. It has been important for reproducing crops used across the African continent, including oil palm, plantain, banana, date, eggplant, pineapple, rubber tree, cassava, maize, sweet potato, yam, and tomato.

- Cloning and in vitro fertilization allow the manipulation of germ cells for animal-breeding programs, genetic-resource conservation, and germplasm enhancement.

- Gene profiling or association mapping tracks the patterns of heritability of variations (alleles) of many genes. The quantitative trait loci (QTLs) collectively contribute to complex plant traits, such as drought tolerance and robust seed production, and understanding of the groupings of QTLs provides insights into how genes work in concert to produce a particular characteristic.

- Metabolomics provides a snapshot of all the metabolites being produced in a plant cell at any given time under different environmental conditions.

Overcoming Biotic Stresses to Crops

Insects and weeds can cause substantial crop losses. Kishore described the first generation of commercial transgenic products, the pest-protected and herbicide-tolerant crops that were first introduced in the United States. In one example, as young plants of herbicide-tolerant soybeans emerge, the field is treated with glyphosate; this kills the weeds, but the crops tolerate the herbicide. The benefits of the method include the savings in time, labor, and energy involved in managing weeds and the ability to avoid tillage, which causes soil drying and erosion. In a second example, pest-protected crops have been genetically engineered to produce a bacterial toxin, an insecticide derived from *Bacillus thuringiensis* (*Bt*), which kills lepidopteran pests of corn and cotton. According to Kishore, many U.S. farmers did not recognize how much the European corn borer affected both the productivity and the quality of their crop until they cultivated *Bt* corn, compared the resulting yields, and saw how much they had been losing.

Transgenic crops have now been widely planted in the United States, China, Canada, Argentina, Brazil, and South Africa and are at varying stages of evaluation or adaptation in many other countries. Some major crops protected against biotic constraints include transgenic maize, cotton, and soybean, but, as noted in the workshop, other transgenic crops are under development. Participants noted in particular the efforts to develop weed-resistant plants and to insert *Bt* genes into pro-vitamin A white starchy sweet potatoes to make them resistant to weevils.

Overcoming Abiotic Stresses to Crops

Although herbicide-tolerant and *Bt* crops are the most common types of transgenic crops, there is great interest in introducing other characteristics into plants to make them more productive in poor agronomic conditions.

Nutrient-Poor Soil

Soil degradation affects one-fourth of agricultural land worldwide (GEF, 2003) and is one of the most important limitations on agricultural production in the developing world. The African landscape is plagued by weathered soils and poor soil fertility (Holden, 2006). Although investment in improving soil fertility is needed, Kishore described how researchers at such companies as DuPont have used plants—for example, corn and arabidopsis—to produce transgenic plants with improved responsiveness to nitrogen. Crops that have been genetically engineered to more efficiently fix nitrogen, and thus reduce the need for external inputs of fixed nitrogen, could enable farmers to lower their production-related input costs while improving crop performance.

Heat and Drought Stress

Water security is projected by the United Nations Population Fund as one of the top global issues in the 21st century (UNFPA, 2002). More than a half-billion people live in countries defined as water-stressed or water-scarce, and by 2025 that figure is expected to increase to 2.4-3.4 billion (UNFPA, 2002). Drought-resistant transgenic crops could be useful in alleviating the demand for water in agriculture. Kishore described DuPont's work on corn varieties that maintain high yields under drought conditions and the development of drought-tolerant millet and sorghum, two staple crops; drought tolerance could have a large effect on agricultural productivity in Africa. It is unclear how well the technology will work under a multitude of field conditions—influenced by factors such as regional and geographic differences—and whether two or more types of stress (such as stress caused by heat and stress caused by drought) will have a compound effect on productivity.

Salinity

Salt tolerance was mentioned by workshop participants as useful in the developing world. Soils are often poor in quality because of salinity, and salt tolerance in crops such as rice and other cereals and vegetables would allow saline soils to be used more productively. Mariam Sticklen, of Michigan State University, described her work on a barley gene that confers salt tolerance in transgenic oats.

Efficiency of Resource Use

Multiple lines of research are being conducted to find the genetic basis of a plant's ability to efficiently use resources, such as sunlight and nutrients. Kishore described research to improve the plants' ability to utilize whatever nutrition is available, starting with sunlight, carbon dioxide, and nutrients in soil. Beans and high-yield rice are two crops being examined for efficiency of resource use.

IMPROVING THE NUTRITIONAL VALUE OF CROPS

Advances in biotechnology have not only shown a potential for improving food production but have broadened the spectrum of available agricultural products (FAO, 2000; Dargie, 2001). Some 2-3 billion people suffer from widespread micronutrient and protein deficiencies, and malnutrition accounts for about 50 percent of deaths among children under the age of 5 (WHO, 1998; Micronutrient Initiative, 2008). The challenge will be to provide them with adequate nutrition.

Food crops that are either conventionally bred or genetically engineered for enhanced nutritional value can be used to alleviate micronutrient deficiencies in the developing world (Bouis, 2002; Toenniessen, 2002). High-carotenoid canola and “golden” rice have been engineered to combat vitamin A deficiency (Guerinot, 2000; Ye et al., 2000) that is the single most important cause of preventable child blindness in developing countries and which affects the health and survival of at least 254 million “at risk” children of preschool age (WHO, 1995). Benjavan Rerkasem, of Chiang Mai University in Thailand, noted that lysine-enriched maize hybrids developed in China are being successfully grown by poor farmers there and in remote border areas in Vietnam and Laos (Prasanna et al., 2001). Crops are also being biofortified with micronutrients such as iron, iodine, vitamin A, and folic acid; and staple crops, such as sweet potatoes, are being enhanced with zinc (Pollack, 2003; HarvestPlus, 2008). Researchers at DuPont are engineering an increase in the nutrient density of vegetable proteins by increasing biologically available phosphates in grains, increasing several essential amino acids, and improving the oil and starch components of seeds. Those are just a few examples of work being done around the world. Dietary diversity, biofortification, and supplementation are other ways to deal with nutritional deficiencies.

In addition to incorporating novel genes into plants, biotechnology can be used to identify genes in native plant populations that could improve human health and nutrition. Researchers with the Brazilian Agricultural Research Corporation (Embrapa), part of the Ministry of Agriculture, have looked for diversity in the carbohydrate and carotenoid content of cassava and discovered a sugary cassava with both a higher sugar concentration and a different starch structure. Those researchers also discovered “golden cassava,” which contains high concentrations of β-carotene, lycopene, and lutein. Carotenoid genes of golden cassava could be bred into other cassava varieties to improve nutritional quality.

IMPROVING FOOD SECURITY

Food security involves more than adequate production in the field. The timing of the harvest, availability of food throughout the year, flexibility in the use of a crop, and ability to store food are important components of food security. Biotechnology can reduce the risk of variability in food availability in several ways.

Post-Harvest Losses

Post-harvest losses can be enormous in developing countries. Between field and plate, reports quote losses of 10–100 percent in some fruits and vegetables in Africa. If genetic resistance to post-harvest pests and fungi are built in, this can increase the ability of farmers to store crops and crops stand a better chance of making it to the market. Biotechnology can also facilitate the preservation of nutrients from farm to plate. For example, cassava juice is high in beta-carotene, but it quickly loses potency when stored. Embrapa researchers have worked with Amazon natives to devise a convenient powder of cassava juice that can be reconstituted into vitamin-rich juice.

Those technological solutions might not, however, be able to compensate for the lack of infrastructure, according to Bongiwe Njobe, director general of South Africa's Department of Agriculture. She described a situation with maize production in Zambia where the absence of roads inhibited the transportation and distribution of maize before the rainy season. Once the rain set in, transport of the maize crop to markets was lost, and the country found itself vulnerable.

Risks to Food Production

Biotechnology can address food security issues by reducing risks to food production in two ways: by increasing the reliability of production and by smoothing supply and demand in rural markets. After harvest in rural areas, there can be a large drop in prices; a severe decrease in the market price of maize in Africa can have a devastating effect on farm families. Anything that can be done to increase storability or to smooth production and consumption throughout the year will have highly beneficial effects on family health, well-being, and opportunities. Transgenic crops can potentially have a sizable effect on smoothing production, according to Kishore, who described Monsanto's work on genes that confer tolerance to chilling-injuries. Cold-tolerant crops could help to increase the optimal timeframe of a crop's production and allow farmers to choose crops that sell later in urban markets and to wait until markets are more favorable for their sale. If poor farmers were able to get seeds into a field 3-8 weeks earlier, they would have more flexibility to escape late-season plant diseases, drought, and pest attacks. They would also have opportunities for staggering crops and planting multiple crops to extend the timeframe when farmers can bring crops to market.

Alternative Uses

Biotechnology can increase the availability of alternative types of crops. Embrapa researchers have developed cassava varieties that meet the specific needs of local communities. For example, cassava has been engineered to produce better glucose syrup and used as beer precursors. Another example of an alternative crop use is the production of plant-administered medications. Vaccines that are based on edible plants[3] may offer the developing world a locally grown, more stable, and less expensive production method compared to conventional pharmaceutical production (Arntzen, 1997a,b; Tripurani et al., 2003).

Increasing the reliability of production creates the possibility for other mechanisms—such as the development of financial systems (including savings accounts, financing of agriculture, and financing of agricultural inputs) and other infrastructure—to stabilize a rural economy and reduce both the risk of crop failure and the financial risk taken by farmers in producing food.

PROTECTING AND PRESERVING BIODIVERSITY

Biodiversity is a term used to describe the array of the world's species, the genetic variability in and among populations of a species, and the distribution of species among local habitats, ecosystems, landscapes, and whole continents or oceans (NRC, 1999). The number of naturally occurring species of plants and animals tends to be higher in many developing countries of the tropics than of industrialized countries of temperate climates. Preserving that biodiversity is important for maintaining the functioning of natural ecosystems, which provide part of the base of natural resources, such as water and pollinators, that supports such human activities as farming. The biodiversity in natural ecosystems is also a source of genetic variability that is useful in crop development, as mentioned in a presentation by Luiz Carvalho, of Embrapa in Brazil. For example, genes that confer resistance to diseases can often be found in the wild relatives of domesticated crops, and these genes may sometimes be used by conventional breeders and molecular breeders to enhance the characteristics of crops. The discovery of diversity in carbohydrate and carotenoid types in cassava is another example of finding valuable properties in plants that can improve human nutrition and health.

The role of biodiversity in natural and managed ecosystems has multiple aspects. For example, some participants in the workshop criticized industrialized models of agriculture and cited how genetically narrow monocultures place crops and agricultural systems at risk for devastation by disease. They advocated for more diverse agricultural production farming systems and greater genetic diversity in crops.

Some in the workshop suggested that applying new agricultural biotechnologies without disrupting the biodiversity in many developing

[3]There are concerns about quality control, potential drug overdose, and other potential risks associated with the use of food crops to produce drugs (Graham, 2000; Coghlan, 2005).

countries presents a serious challenge. The capacity does not exist, they believe, to look critically at what may or may not be beneficial in particular settings.

Several workshop participants expressed their concern about how the introduction of transgenic crops would affect gene flow, agricultural productivity, and the natural environment. Rerkasem brought up the example of weedy rice, believed to be a natural hybrid of cultivated and wild rice species or a result of the de-domestication of cultivated rice (IRRI, 2008). The flourishing of weedy rice in Thailand's central rice bowl reduced yields of cultivated rice, illustrating the risk of genetic exchange between cultivated and wild varieties and how they can have unpredictable outcomes. According to Rerkasem, because gene flow is unpredictable even in wild species, mechanisms of addressing biosafety concerns will need to be considered before transgenic crops are moved from the laboratory to the field to ensure that they do not reduce natural biodiversity.

Workshop participants described research that is under way to develop safeguards to block gene flow; according to some, the technology already exists to prevent gene escape. Richard Meagher, of the University of Georgia, described plants that can produce sterile pollen or seeds (for example, sterile because of thiamine deficiency) and plants that can be engineered for male or female sterility. Sticklen mentioned that another method to block gene flow is to transform new genes into chloroplasts rather than into nuclear DNA; chloroplasts are maternally inherited in most flowering plants, and the new genes will not be found in pollen.

Biotechnology can be used for more than the creation of genetically engineered crops: it can be used to preserve biodiversity and aid in genetic resource conservation efforts. Carvalho suggested that surveys are needed to determine the status of existing biodiversity, evaluate its value and importance, and identify endangered species and genes. On the basis of the survey results, he argued, measurable targets for the sustainable use and conservation of various species could be set. An overarching challenge is the lack of human capacity on the ground to monitor what happens to biodiversity when new living systems are introduced, what happens in the long term, whether there are benefits, and whether there are serious disruptions of ecological life.

Work is under way in several countries to characterize indigenous plant varieties and animal breeds with biotechnologies to document and safeguard biodiversity. For instance, Carvalho described an Embrapa program in native Krahos communities in Brazil that had lost their traditional plant varieties and faced community collapse due to lack of food. Embrapa, which had been collecting samples of biodiversity in the region, had the traditional landraces in its gene bank and was able to return the original landraces to the Krahos. Embrapa researchers then teamed up with the Krahos to rescue traditional knowledge associated with the Krahos agricultural system, to educate and train the residents in other agricultural methods, and to collaborate with them to organize and maintain a germplasm collection. The use of field-plot germplasm collections and in vitro tissue-culture methods gave residents a powerful tool to preserve regional biodiversity. This example illustrates how the techniques of biotechnology have been used to conserve biodiversity and the cultural heritage of native people.

ENHANCING NATURAL RESOURCE CONSERVATION

Agricultural biotechnology can have secondary effects that enhance natural resource conservation and protect the environment. By developing drought-tolerant crops, researchers can help farmers to conserve water resources. Crops that are genetically engineered to produce *Bt* toxin require less spraying of pesticides, and reduction in spraying reduces the potential environmental harm caused by pesticides. Agriculture accounts for more than 30 percent of global greenhouse gas emissions (FAO, 2006a); however, herbicide-resistant crops promote no-till cultivation practices which help to reduce soil erosion, emissions of greenhouse gases, and carbon loss (Robertson et al., 2000; Lal et al., 2004; Zheng et al., 2004).

Renewable Energy

Workshop participants noted that biotechnology could play a major role in addressing the world's energy and resource needs in the future. Trees that are genetically engineered to grow faster could help to meet the world's demand for industrial wood and potentially reduce the need to harvest trees from natural forests. New plastics made from biodegradable plant polymers may one day provide an environmentally safer alternative to traditional plastics made from fossil fuel. Global energy demands are forecasted to increase by 40 percent in the next 20 years (EIA, 2003). If energy demand is met by fossil fuel use, much more carbon dioxide will be produced. Agricultural products can be engineered to provide fuel alternatives in the form of biodiesel and biofuel: Sticklen described research to engineer rice straw, a major environmental contaminant in developing nations, so that it is biologically broken down into useful alcohol-based fuels.

Phytoremediation

Many populations are regularly exposed to toxic substances, such as arsenic and mercury, and thus live in environments that are deleterious to their health. In Bangladesh alone, an estimated 57 million people—44 percent of the population—are at risk of exposure to toxic concentrations of arsenic in drinking water (UNESCO, 2008). About 6 million people in the Amazon are at risk of methylmercury poisoning from the nearly 5,000 tons of mercury deposited in tributaries as a result of gold mining (Veiga, 1997; Harada et al., 2001). Many land and water resources are contaminated on a global scale and cannot be remediated by physical methods, but biotechnology-based alternatives could provide solutions to problems of environmental contamination.

For phytoremediation, Meagher described one system for cleaning up the environment that uses native plants to degrade organic pollutants, such as trichloroethylene and polycyclic aromatic hydrocarbons, and process them into less harmful molecules. Elemental pollutants—such as arsenic, mercury, and radionuclides—cannot be readily metabolized or broken down; however, plants can extract, concentrate, and accumulate those pollutants from the soil for aboveground harvest and disposal. Determining which plants to exploit for that purpose and finding safe disposal sites is part of the research. The plants used to accumulate the pollutants would ideally be nonfood plants—something inedible—to prevent accidental poisoning and would grow between productive food crops so that farmers could maintain land productivity.

Genetically engineered phytoremediants have already shown promising results in initial field tests. The first field trials of a native hybrid accumulator of nickel have successfully extracted nickel. Researchers have also successfully used RNA interference to inhibit plants from converting a form of arsenate into another form that collects in roots; such inhibition allows plants to transport arsenic to their shoots and leaves, which can then be harvested. Cottonwood trees are among the several species that have been engineered to grow in mercury-contaminated soil and remove high concentrations of mercury.

3

Challenges and Future Considerations in Realizing the Global Potential of Agricultural Biotechnology

If a common theme emerged from the workshop, it was that biotechnology constitutes only one part of a complex and nuanced set of investments needed to enhance crop productivity, increase yields, and ultimately ensure food security. The movement of biotechnological innovations into farming systems of the developing world faces several challenges, including simply knowing what crop characteristics farmers need. Proponents of genetic improvements in crops do not always appear attuned to the perspectives of poor farmers and have not thoroughly assessed their needs, so they are limited in their ability to forecast how farmers would benefit. In addition, unless developing countries can solve some of their difficult social, economic, and infrastructure problems, they may never realize the benefits of agricultural biotechnologies that could help to improve productivity and align farmers with modern agricultural practices. The difficult question of which investments to address first could not be answered easily by the workshop participants. In fact, as the workshop progressed, participants identified several key challenges that seemed to require simultaneous attention if biotechnology were to be successfully introduced. The interconnectivity of those challenges formed the core of the workshop discussions.

CHALLENGE 1: DEVELOPING APPROPRIATE AND AFFORDABLE TECHNOLOGIES

There is a need to develop technologies that complement existing farming systems and native crops, to provide them at affordable prices, and that are safe for humans and the environment.

Locally-developed applications need to be designed to meet local conditions and user needs. It cannot be assumed that existing applications can simply be transferred: many, if not most, existing biotechnology applications are not appropriate for the conditions in developing countries. For instance, herbicide-tolerant crops have been slow to penetrate Africa and South Asia because the tolerant varieties are not adapted to crops and conditions that are most relevant to developing countries, and more importantly, no-till technologies in small farm production systems have been difficult to develop.

Diverse Farming Systems

The agricultural landscape in the developing world consists of diverse crops and various types of farming systems that differ depending on locality, geography, and availability of natural resources. Bongiwe Njobe, director general of the Department of Agriculture in South Africa, contrasted the homogeneity of Asian farming systems at the start of the Green Revolution with the diversity of African systems today. She noted that a study by the InterAcademy Council identified four existing farm systems in Africa that have the greatest potential to increase African food security (see Box 3-1) and asserted that the nature of these crop systems needs to drive the choice of biotechnology applications rather than shaping agriculture to fit the available applications. Factors that might affect which crops are selected for genetic engineering and which specific traits are modified depend on the systems, some of which are rain-fed and others irrigated, some of which center on growing maize (tropical maize, not the temperate varieties grown in North America), and some of which are focused on root crops or trees. Many workshop participants therefore believed that agricultural biotechnology could be a "rainbow revolution" that would apply a broad array of technologies and innovation systems where they are most needed.

Native Crops and Local Needs

Orphan Crops

Crops with relatively little global commercial potential—which include cassavas, east African highland bananas, cowpeas, and yams—are

Box 3-1
The Most Promising African Farming Systems for Increasing Food Security

An InterAcademy Council report examined several farming systems in Africa and concluded that four existing systems showed the most promise for increasing African food security. The selection of the four systems was based on the potential for reducing malnutrition and for increasing agricultural productivity.

The maize mixed system is the most important food production system in east Africa and southern Africa and similar systems are found in west Africa, covering 10 percent of land area in sub-Saharan Africa and used by 15 percent of the agriculture population there. Maize is the main crop, and cash sources include cattle, small ruminants, poultry, tobacco, coffee, cotton, migrant remittances, and off-farm work. This system is currently in crisis because of shortages of seed and fertilizer.

The cereal/root crop mixed system covers 13 percent of land area and is used by 15 percent of the agriculture population in sub-Saharan Africa. The system shares some characteristics with the maize mixed system, with such cereals as maize, sorghum, and millet as staples; but it differs in that root crops such as yam, cassava, and legumes are present when animal labor is absent. The system is defined by relatively low population density, abundant arable land, poor communication infrastructure, and higher temperatures. The main vulnerabilities are due to drought, decline in soil fertility and structure, and weeds.

The irrigated farming system is linked to areas with surface water resources, but it is found across all zones. It covers 2 percent of land area and 17 percent of the agriculture population in middle east and north Africa and 1 percent of land area and 2 percent of the agriculture population in sub-Saharan Africa. The system is based primarily on rice, cotton, vegetables, rain-fed crops, cattle, and poultry. Crop failure is generally not a problem, but the system is vulnerable to water shortages, scheme breakdowns, and deteriorating input-to-output price ratios.

The tree crop-based system relies on the production of industrial tree crops, primarily cocoa, coffee, oil palm, and rubber; it covers 3 percent of land area and 6 percent of the agriculture population in sub-Saharan Africa. Food crops, such as maize, are planted between tree crops for subsistence, and root crops, such as cassava and yam, are the main staples. Tree crop and food crop failures are not common. The main vulnerabilities to the system are related to population pressures on natural resources, declines in trade and market share, and withdrawal from industrial crop research and extension.

SOURCE: InterAcademy Council, 2004.

grown in many developing countries for subsistence and are staples that meet local food needs and demands. Some of these "orphan crops" are cash crops, such as the sugar cassava in Brazil, that help farmers to purchase nonfood items such as medicine and books. But these orphans have received little attention from biotechnology seed companies in the industrialized world. Among the reasons that transgenic seeds have not been successfully adopted by farmers in developing countries is that the available seeds do not reflect their region's local crops or the natural resources available to grow them. A few workshop participants suggested that a genetically altered toxin-free *Lathyrus*—a protein-rich legume grown in Asia—might be of more help for small farmers; whereas the split seeds of *Lathyrus* are soaked overnight to clear them of toxins, the danger of toxicity is not eliminated for all its potential uses.

Weeds and Labor

Engineering of crops to be herbicide-tolerant reduces the amount of time spent on manual weed control, an activity that in the developing world exceeds by far any other human activity related to agriculture. However, as Suman Sahai, a representative of the Gene Campaign, pointed out, India has surplus labor, so herbicide-tolerant crops can take wage-labor opportunities away from rural women. Furthermore, what constitutes a weed is subjective and can differ between cultures. The purported weeds growing among crop plants are collected by women for use as animal feed or as medicinal plants for local human health and veterinary care. The potential conflict between labor-saving innovations and job security in developing countries is often overlooked by technology developers, but increased productivity by definition means doing more work with less input, and labor is one input. The question is whether there will be other ways for displaced laborers to spend their time to obtain income.

Affordability and Accessibility

Workshop participants agreed that technologies and products need to be available at affordable prices especially for small farmers and the poor. If small farmers cannot pay for or sustain a technology or product, it will not be useful, regardless of its potential. Transgenic seed is expensive for a small farmer, and the extra funds expended represent an opportunity cost. Transgenic crops, such as *Bt* (*Bacillus thuringiensis*) cotton, can provide better yields than local varieties because they are able to overcome specific constraints, such as insect pests, but they may not perform as well as local varieties if environmental conditions—for example, water availability—are not optimal. Therefore, farmers take a risk in investing in transgenic crops. Benjavan Rerkasem, of Chiang Mai University in Thailand, noted that in addition, there is little incentive for investment if products that are developed specifically for the poor, such as micronutrient-enriched grain, cost the farmer more but do not provide greater yield or command higher prices. The challenge will lie in providing incentives to farmers and other components of the production and marketing system to maintain affordable products and create a sustainable marketplace.

CHALLENGE 2: DETERMINING PRIORITIES FOR BIOTECHNOLOGY

National leaders often need to make decisions about priorities with limited financial resources, user input, and scientific understanding.

Decision-makers in developing countries who want their agricultural systems to benefit from biotechnology have a difficult task. They try to formulate a strategy to encourage the development of appropriate applications of biotechnology when they have few mechanisms for knowing what is most needed by farmers or wanted by consumers and with limited financial resources to pursue an agenda for introducing transgenic crops from outside sources or developing them internally. In their efforts to define a research agenda that is scientifically sound, decision-makers need scientific advice—something that is often lacking in developing countries.

Determining Research Needs

Developing a strategy for improving agriculture requires a decision of which research directions to support. Many workshop participants felt that with regard to biotechnology, leadership in setting priorities has not been coming from the governments of developing countries nor has it been determined by the needs of subsistence farmers, as suggested by Bonjiwe Njobe. Rather, leadership has stemmed from the investment, development, and modernization of biotechnologies from the private sector where the emphasis is on market forces to drive the process. The implication of a supply-led market approach is that a product is often created and sold on the basis of its branding by its producer rather than the stated desires of consumers or the quality-assurance pronouncements of the regulatory system. Because of the profit motivation, some participants believe the private sector may move products to market and sell them to farmers before the risks and benefits related to the products are sufficiently evaluated.

Government officials that want to lead in setting the agenda for agricultural biotechnology have little internal guidance in making decisions, a task that is not made easier by potentially conflicting agricultural priorities. As Njobe stated, the crop sector may want genetically engineered maize, the livestock sector may want to pursue organic markets, and the two goals may not be compatible. More often than not in developing countries, however, getting input on priorities is rare because there are few mechanisms for engaging farmers, especially small-holder farmers. According to Rebecca Nelson, of Cornell University, the academic research community has traditionally done a poor job in looking at culinary and post-harvest characteristics, properties that help plants to compete with weeds, and other elements that are important in field settings but may not be recognized by laboratory researchers.

It is crucial that government leaders keep the bigger picture in mind when determining priorities so that they do not promote a scientific solution to a problem that can be solved more easily by other kinds of investment. Jean Halloran, of Consumers Union, cited a meeting with Mozambique colleagues that illustrated how regional hunger problems could be solved. Her colleagues noted that while some regions of Mozambique were experiencing drought, other parts of the country were not affected and were able to produce healthy crops. Although scientists might want to address the problem of drought by engineering drought-tolerant crops, the problem of hunger could be better solved by improving north-south transportation networks. Halloran concluded by stating that "it would probably take a much smaller investment in roads than in scientific research to address the problem." Don Doering, of Winrock International, added that there are a few good global or regional models for estimating the value of some of the traits that crop breeders have discussed and that such models would be useful in helping decision-makers decide between, for instance, investing in the development of a drought-tolerant crop and funding the installation of irrigation systems.

Resource Limitations and Priorities

Across Africa, agriculture usually receives less than 5 percent of most government budgets (World Bank, 2008) because support for scientific investment must compete with other urgent political, economic, and social priorities. In the science budget itself, all types of research compete for scarce funding. Workshop participants expressed a concern that in a resource-constrained environment, existing scientific efforts on important agricultural problems will be superseded by an emphasis on modern biotechnology. John Lynam, of the Rockefeller Foundation, observed that the Consultative Group on International Agricultural Research (CGIAR) has shifted research investment away from methods of soil, crop, and resource management and toward breeding and biotechnology and that there is also movement away from whole-plant methods toward molecular methods.

Nelson added that conventional breeding has delivered remarkable improvements to crops such as Brussels sprouts, kohlrabi, kale, broccoli, cauliflower, and cabbage and that nothing produced by transgenic technology has been "quite so unbelievable" as the successful transformation of those vegetables by nontransgenic means.

Many participants agreed, suggesting that investment in molecular biology has been lopsided over the last few decades and has left many developing countries with a large gap in scientific expertise, ranging from whole-plant physiology to plant breeding. For example, Rerkasem mentioned that rice breeders are becoming "extinct" in Thailand—a situation that will work against the introduction of biotechnology because breeding is still needed to incorporate promising new genes into local varieties of rice.

Moreover, Lyman said, priorities have to be established to bring transgenic innovations and breeding programs together, and this is difficult because current breeding programs are highly decentralized and focus on a multiplicity of crops grown in diverse agroecologies. "The question," he said, "is how to make decisions on what crop is to be transformed with biotechnology and then on how transformation will be applied in a wide array of breeding programs."

CHALLENGE 3: ENGAGING THE CITIZENRY

Public participatory mechanisms are needed to gauge needs and to address concerns.

Implementing a democratic decision-making model and soliciting public participation can result in more sound decisions, the development of technologies that are locally adapted and better suited, and a bridging of the rhetorical divide surrounding agricultural biotechnology. Honest public discussions are crucial for moving technologies forward because they may reveal concerns that governments and the scientific community have not expected. Mechanisms that provide a sense of transparency can aid the public in understanding, accepting, and adopting new technologies.

Transparent Decision-Making Processes

A decision to introduce transgenic crops may involve economic and environmental risks, and nations need a legal framework for evaluating the risks, communicating them to the public, and justifying decisions. A perceived lack of transparency in a government's decision-making process will cause citizens to become distrustful of government authority. Without a sufficient process, even the most well-intended efforts of the international research community will be suspect, according to Phelix Majiwa, of the African Agricultural Technology Foundation in Nairobi, because it will not be evident that the efforts are being driven on behalf of local needs. Legal avenues for people to get information need to be created, according to Suman Sahai. The United States has a free press and the Freedom of Information Act, but in many other countries the public has no way to get such information.

The public also needs confidence that its own government has the scientific capability to conduct safety assessments of biotechnology products. Most developing countries are too small to set up their own biosafety protocols and screening procedures, so their policy-makers look to others who have already established biosafety programs for guidance and assistance. These countries also rely on regional centers, laboratories, and procedures from more advanced countries in their region for assistance.[1] In 2003, the Codex Alimentarius Commission adopted guidelines, developed over several years by a Codex task force, that describe an internationally-agreed approach for assessing the safety of genetically modified crops for human food uses. The Codex guidelines are intended for use by governments developing food safety oversight systems for foods derived from such crops.

Efforts such as the GMO Guidelines Project (GMOERA, 2008) aim to help developing countries to establish approaches and methods for biosafety assessment of genetically modified organisms. The project, described by David Andow of the University of Minnesota, was funded by the Swiss Agency for Development Cooperation and it brought together public-sector scientists from all over the world to help local scientists to build that capacity.

Processes for Public Participation

Even if a regulatory process is in place, products that are approved and introduced into the market may be held in suspicion. Countries that do not broadly consult or involve their citizens in public discourse—especially as it pertains to novel scientific applications, such as agricultural biotechnology—find that their citizens question whose interests deci-

[1]The Food and Agriculture Organization of the United Nations (FAO) has also developed guidance for its member governments, especially developing countries, to help them use sound and consistent decision-making frameworks when confronting biosecurity issues (FAO, 2006b, 2007).

sions serve in the long term. Introducing a new product or technology without the public's consideration can perpetuate the image of ambiguity in decision-making and therefore perpetuate the belief held by many in the developing world that the "biotechnology agenda" is set by the rich industrialized nations to exploit the poor in the developing world.

In some countries, consumers have demanded labeling as a way of allowing them to decide whether or not to accept this technology. There is a need for consumers to be aware of the huge differences in degree of possible environmental and human risk from different technologies. Given the enormous difficulties and the cost of labeling in small country food and feed systems, consumers will need to be made aware of both and avoid "blanket" requirements for labeling.

Many international agreements—including the Cartagena Protocol on Biosafety, which grew out of the Convention on Biological Diversity—mandate public participation in their decision-making process with respect to transgenic technologies. Many workshop participants, however, expressed concern that developing countries have fallen short in that respect. As one workshop participant observed, both the advocates of biotechnology and those who are violently opposed to it may be sponsored by external sources, and the voices of the local populations most affected by the proposals for agricultural biotechnology are often unheard.

It is crucial to engage the public in scientific discourse well before the regulatory stage so that citizens understand and sense ownership of their country's scientific decisions. Public forums can shed light on issues not anticipated by policy-makers and scientists and can provide valuable input into decisions as to the most appropriate technologies to pursue.

Farmer Participation

One participant described her recent involvement in a consultation workshop in west Africa on millet- and sorghum-based systems. She said that the farmers' representative told her, "We want a sheep's head; you bring us a dog's head." Because of the mismatch between technology development in agricultural biotechnology and technology adoption by users, a more accurate way to assess needs and challenges is to involve relevant stakeholders directly at various stages of the decision-making process.

Matching needs with capabilities is itself difficult. Farmers often have trouble in conceptualizing the sorts of things that biotechnology might be able to accomplish for them. Likewise, scientists may have trouble in translating generic characteristics, such as "improved quality of flour," into specific traits that research can focus on.

Rural and tribal communities are often the most difficult to engage in public participation activities, and some workshop participants argued that not enough attention has been paid to developing structures and methods of communication. Most of the methods used to inform and educate the public about agricultural biotechnology include websites and registers, but most rural communities in developing countries do not have access to the Internet or even print media, and most of the population is illiterate.

Illiteracy does not equate to lack of wisdom; many in developing countries who cannot read or write have enormous reserves of knowledge and can be valuable participants in a discussion of crop improvement. Their trust is an absolute necessity if the new technologies are to benefit them. The foremost thing to keep in mind, according to Sahai, is that there is a large information gap to be bridged by communication methods to accommodate not just the local language but the local idiom. Aside from lacking access to written literature and being widely dispersed geographically, farmers are busy—many are women who also have child-care obligations—so their daily schedules are a consideration when information is transferred.

One method that has been tried with success in Asia and in some parts of Africa, Sahai mentioned, is street theater and roadside theater containing caricature and skits, where information is turned into accessible packets that people can immediately respond to. Theater groups, nongovernment organizations, and governments will all need to rise to the challenge of creating space where a formal structure can be used for activities to foster public participation. Sahai added that "there is no point in sitting in a conference room and hoping that tribal communities can come inside and start participating. It's intimidating."

Cultural and Religious Issues

New technologies can be perceived as threatening cultural and religious traditions, according to some participants. For example, it is possible that Muslims or Hindus will not be persuaded that swine- or cattle-derived DNA inserted, for example, into sheep or a plant is merely a generic molecule; Germans will view genetic manipulation from the perspective of their history; and Indonesians will filter information through lenses shaped by their cultural heritage and cultural preferences. Societies differ in their perceptions of what is natural and unnatural, acceptable or unacceptable. Many workshop participants suggested that it is important for policy-makers to recognize and respect the cultural and religious sensitivities of citizens that may place limits on agricultural biotechnology. In India, according to Sahai, "the whole concept of taking part in decision-making" in all sectors of society is becoming important to citizens. At the end of the day, she said, you cannot simply dispense with the right of choice that almost all nations grant to both consumers and farmers.

Biotechnology and the Long-Term Public Interest

Developing countries are not alone in the challenge of involving the public in discussions about genetically engineered crops. Researchers in developed nations have faced some of the same issues about transparency and inclusiveness. Piet van der Meer, of Horizons *sprl* Co. in Belgium, noted that it is easy to say that public participation is needed, but it is extremely difficult to implement: "I have had many, many, many hearings over the years on antibiotic resistance and herbicide resistance and so forth. And you can hold one meeting one day, and the next day more people will come and say we have not been consulted." As another example, Harald Schmidt, of the Nuffield Council on Bioethics in England, described a website that his organization created to solicit views on genetically modified (GM) crops; 38,000 people (of 60 million in the UK) registered their views on the site, but Schmidt asked, "How representative of the debate is that?"

According to participants, the experience of the developed countries demonstrates that a period of public education and familiarization is often needed *before* people can be actively brought into decision-making structures. And before biotechnology applications are approved and accepted, it is crucial to inform the public about their benefits and risks.

There are also likely to be concerns that agriculture will come to be largely controlled by large transnational corporations that produce and distribute transgenic seed, potentially harming small farmers in the developing world and disrupting social structures. Those issues require frank discussion between policy-makers and farmers. Calestous Juma, of Harvard University, noted that in Africa, instead of seeing farmers saving seed, he witnessed a small-market structure of women who grew seed and sold it. That attests to the power of markets, but some participants wondered what will become of those women who rely on the practice of saving seeds when transgenic seeds—some which are self-terminating after one season and many which are protected as intellectual property—are introduced.

CHALLENGE 4: BUILDING SCIENTIFIC AND LOCAL CAPACITY

Investment is needed to build and strengthen national scientific expertise in developing countries.

Scientists are needed to develop, evaluate, and implement advances in agricultural biotechnology, and there is a critical need to build national bases of scientific expertise in developing countries. Although technological innovations can be promoted by external organizations, workshop participants suggested that national and local scientists will have a better understanding of a nation's strategy for agricultural development, of the needs of farmers, and of the value of improving specific traits related to the performance or marketability of a particular crop or animal. Policymakers investing in national research initiatives would be well served by fostering a new generation of scientific advisers for biotechnology.

Moreover, being much closer to the environments in which genetically engineered organisms will be used, local scientists not only will be more likely than outside groups to focus their own research on relevant animals, crops, and traits but will be in a better position to recognize and evaluate the potential risks posed by the introduction of engineered organisms, given the specific ecosystems into which the modified organisms will be introduced.

It will take time and commitment to build the necessary scientific expertise in government agencies, national universities, and other research institutions. Being trained abroad is not sufficient to establish the capacity needed in the developing world. "So many people from the developing world have been trained in America, in Europe, in Australia," said one participant, "but the quality of agricultural research in the developing world is still not very good. And I base that not just on my own judgment but on what farmers told me." Bonjiwe Njobe added that scientists need additional training in working in multidisciplinary teams so that they can take into account all the diverse factors related to the use of biotechnology.

A notable gap in the scientific capacity in many developing countries, according to more than one workshop participant, is the inability to move transgenes engineered into "elite" germplasm (a variety of a crop that is used in experimental settings) into locally adapted germplasm of the same crop. Without that process, which involves conventional breeding, the benefits of biotechnological advances are not fully captured for local applications. If local scientists are not able to introduce a novel gene into local varieties, farmers are forced to rely on whatever variety seed producers make available, not the varieties that have proved hardy under local environmental conditions.

There are, then, at least four roles for scientists in developing countries with regard to agricultural biotechnology: to advise government on research priorities, to engage actively in research and participate in the development of improved crops and livestock, to act as critical reviewers of the human safety and environmental impact of applications to introduce biotechnology products into the field, and to participate in technology transfer and extension. Communicating how biotechnology crops are to be grown might be challenging, a participant noted. For example, it is not clear that farmers who purchase *Bt* crops will understand why they must plant 20 percent of their land in non–genetically engineered crops to reduce the emergence of resistant insects. A widely held view at the workshop was that support for extension in developing countries had declined precipitously in recent years and needed to be restored.

CHALLENGE 5: DEVELOPING SUSTAINABLE PARTNERSHIPS

Partnerships can be vital in stimulating research in resource-poor countries, but it is important to recognize the goals of each partner.

Once research priorities are set, asked Ann Thro, of the U.S. Department of Agriculture, how are the new technologies going to be developed, and who is going to pay for them? Workshop participants agreed that although the vast majority of agricultural research in developing nations is performed by the public sector, public funding alone will not be sufficient to bring biotechnology innovations to farmers' fields even if the current decline in public funding is reversed. Others added that because of the profit motive, the private sector often rushes to move products to market and sell them to farmers before the risks and benefits related to the products are sufficiently evaluated.

The need for partnerships between public and private entities in agricultural biotechnology projects echoed throughout the workshop, and there was lively debate about the benefits and risks involved in the partnerships.

The Pros and Cons of Public-Private Research Partnerships

Private-sector collaborators often bring funding, intellectual property, technical knowledge, and training to a partnership. The public sector, asserted Rerkasem, could learn a lot from the private sector about how to manage agricultural research. Ganesh Kishore, of DuPont, described the Chura community project in Kenya as a good example of a private-public endeavor. The partnership propagated disease-free bananas in tissue culture. "We are not nameless, faceless corporations," he said, "and we want to be engaged in the community as effectively as possible."

Nations potentially benefit in multiple ways when a private-sector partner is found within their borders. The national agricultural research systems of large developing nations—such as China, India, and Brazil—have collaborated with private companies in those countries, but it was observed that it is much more difficult for that to occur in small countries, such as Zambia, where the private sector is not robust enough to undertake cutting-edge research.

Some workshop participants worried that public-sector investigators could lose their independence and integrity while working with the private sector and become no more than "the lowest-paid members" of a private-sector research effort that might not reflect national public priorities. For instance, one participant observed that when Kenyan researchers collaborated with private seed companies, the focus of the research was on developing hybrid maize, a product that is targeted more at large-scale farmers than at resource-poor small holders who rely on open-pollinated crops. She argued that "partnership norms" were needed to guide public-private collaborations.

Different Motivations, Different Roles

It was pointed out that although companies may have know-how that can benefit developing countries, they are nonetheless profit-driven businesses, and leadership of many companies emphasizes the influence of market forces on the direction of research efforts. Private-sector venture capitalists have a bias toward supporting innovations in large-acreage row crops because that is where the financial return will come from.

That leaves a gap, said Kishore, not only in improving orphan crops but in projects involving fruits, vegetables, forestry, energy, and the environment—sectors where biotechnology holds huge promise. The question is how the gap can be filled. Carl Pray, of Rutgers University, suggested that in the absence of local scientific expertise, the private sector could be given incentives by governments and other funders to focus research on the pressing agricultural problems in the near term.

The work of the private sector is not limited to its companies; public and private donors fund initiatives such as the CGIAR research centers. From the perspective of Kym Anderson, of the World Bank's Development Research Group, those centers should be more engaged in agricultural biotechnology for poor countries; without their involvement, there would be a long delay in the implementation of innovations in developing countries. However, several workshop participants emphasized that the level of funding for public-sector research and the CGIAR centers, which played such a large role in the Green Revolution, was perceived to be low. Njobe noted that the InterAcademy Council study panel that looked at African agriculture recommended that countries pool their resources to create African Centers of Agricultural Research Excellence that would perform research on subjects of high continental and regional priority.

Another participant suggested that foundations, many of which are based in the industrialized world, could consider funding partnerships between the public sectors of developing countries instead of the typical model of "north-south" collaboration. African and south Asian countries would have much more in common with an entity like Embrapa than with a U.S.-based university or agency.

It was also suggested that grants, prizes, and contracts are potential means of encouraging innovation in a particular direction. Governments or foundations can use contracts if they have a good understanding of the qualities of a product that they want to have produced but do not know what kind of research organizations would be best to do the research. Prizes are better for stimulating work on difficult tasks. One example is the Earth Institute at Columbia University, which promotes sustainable development in Africa by offering to reward innovators with cash payments. The prizes are given for the demonstration of innovations in the field, not just in the laboratory.

Finally, Lynam described what he viewed as international public goods, regional public goods, and national public goods and called for greater thought and discussion about the appropriate roles of different kinds of investors in supporting the development of each type of public good.

CHALLENGE 6: ENGAGING IN GLOBAL DIALOGUE ON AGREEMENTS AND PROTOCOLS

Scientists and lawyers in developing nations need to participate in discussions and negotiations about biodiversity, biosafety, trade, and intellectual property rights to ensure that agreements can be implemented in ways that help their nations meet their goals.

Biodiversity and Biosafety

There is concern that genetically engineered crops will cross with wild relatives and allow transgenes to move into the environment and potentially alter natural ecosystems. Many participants cited examples in which escaped transgenes had little effect on their environments, but if a transgene were to confer a selective advantage, it could alter wild ancestors and effectively reduce natural biodiversity, although to what degree is hotly debated. The Convention on Biological Diversity and the Cartagena Protocol on Biosafety outline international procedures to address some of the biodiversity and biosafety concerns (see Box 3-2).

A National Research Council report entitled *Knowledge and Diplomacy: Science Advice in the United Nations System* notes that although govern-

Box 3-2
International Agreements on Biodiversity and Biosafety

Convention on Biological Diversity

The Convention on Biological Diversity (CBD) is an international agreement that provides a framework for building regulatory systems to protect biodiversity. The CBD, which grew out of the 1992 Earth Summit in Rio de Janeiro and began enforcement in December 1993, is a comprehensive approach to biodiversity conservation, the sustainable use of natural resources, and equitable sharing of benefits of genetic resources. It addresses biosafety through guidelines that protect human health and the environment from the potentially adverse effects of biotechnology and its products while providing for technology access and transfer.

The convention was developed through a series of intergovernment negotiating meetings and has been signed by many developing countries. In ratifying the CBD, governments have stated their commitment to developing national biodiversity strategies and action plans and to integrating them into broader national plans for the environment and development.

Cartagena Protocol on Biosafety

On January 29, 2000, more than 130 countries adopted a supplementary agreement to the CBD known as the Cartagena Protocol on Biosafety. The protocol is designed to protect biodiversity from risks posed by living organisms that have been modified through modern biotechnology. It establishes a procedure for an advanced informed agreement by signatory countries whereby each would be informed of the potential risks posed by living modified organisms before such organisms could be imported into the countries. Recognizing the lack of scientific certainty as to the effects of living modified organisms on biodiversity and human health, the protocol references a precautionary approach and reaffirms Principle 15 of the Rio Declaration on Environment and Development. Furthermore, the protocol provides a Biosafety Clearing-House to facilitate information exchange and to assist countries in implementing the protocol. It does not affect trade in processed foods or pharmaceutical products that contain genetically modified organisms. The protocol entered into force on September 11, 2003.

SOURCE: Cartagena Protocol, 2008; CBD, 2008.

ments strive to use the best available scientific and technical information to guide biosafety negotiations, no systematic efforts have been made to compile available knowledge on the subject, so the direct contributions of government delegates are usually the only scientific input (Gaugitsch, 2002; NRC, 2002b). The report mentions that existing studies on the safety of genetically engineered crops for human health, the environment, and socioeconomic systems continue to be a major issue of public concern and continue to be subject to divergent interpretations and conclusions (Gupta, 2000; NRC, 2002b). The report concludes that "the persistence of varied interpretations of the available information illustrates the need for scientific assessment to guide discussions and negotiations on major issues of international interest" (Susskind, 1994; NRC, 2002b).

Many workshop participants felt that although the intentions of the convention and the protocol were appropriate, the implementation left much to be desired. Lynam pointed out that different interest groups and government sectors often participate in different components of treaty arrangements but do not interact to discuss their implications fully. As a result, smaller developing countries are unable to respond to regulations in a coherent and consistent way, much less to enforce them. Juma added that it was generally difficult for developing nations to create regulatory frameworks before they have any capacity to be involved in biotechnology themselves: "It's almost like trying to design rules and regulations for governing swimming pools in the Sahara."

Majiwa pointed out that in many countries the lawyers do not play a large part in the debates about biotechnology regulations and guidelines. As a result, he explained, their posture is to wait to see whom they can take to court. "I believe this is going to drive very many African countries behind," he said, "particularly when there is massive introduction of GM products into the market." He stressed the need to bring the legal community into the discussions that lead to the implementation of regulatory regimes.

Van der Meer emphasized the importance of public-sector scientists' participation in developing national policies on biotechnology: "They should not only be aware of the existing rules; they should be involved in making the rules. They should take a far more active role." He also urged public-sector scientists to become involved in international negotiations on the biosafety protocol. In the past, he noted, nongovernment organizations and the private sector were well represented in the negotiations, but the biggest stakeholders in the outcome—scientists in public-sector research—were not there. "That the protocol is adopted and enforced does not mean that it is over. There will be many, many years of negotiations on how to function in this, and it is crucial that the public sector be part of that."

However, the fundamental problem, as was discussed, is the lack of scientific capacity, as a result of which many developing countries are uncomfortable with the effectiveness of their own regulatory and control systems. Participants gave many examples of the illegal spread of genetically engineered crops across Asia, India, and China. Enforcement costs can be high and need to be figured into the cost of regulations. One participant recommended that the United Nations and other organizations help by monitoring the implications of new regulations in developing countries and comparing the time and costs of particular regulation with their benefits. Such analysis might assist governments in developing policies for the introduction of biotechnology and the protection of biodiversity.

Resolving Trade Issues

Many groups have opposed the use of agricultural biotechnology, and some nations have responded to the opposition by placing import-market restrictions on genetically engineered crops. The European Union (EU), Korea, and Japan have restrictions on imports of genetically engineered crops and seeds. In 1999, for example, the EU imposed a "de facto moratorium" on import of GM products from the United States, Canada, and Argentina that had not been approved for sale in the Union. In 2003, the United States and its allies filed a suit in the World Trade Organization (WTO) against the EU for undue delay in the approval of GM products.[2]

Agricultural commodity trade can be affected by a variety of government policies, according to Anderson, one of which includes the requirement to label GM foods. He argued that developing countries are less likely to adopt GM crops out of fear that their access to large foreign markets will be curtailed. For African countries, he asserted, a consequence of avoiding the products is that they forgo potential gains by their own farmers and domestic consumers; they produce less food than

[2]In 2006, the WTO ruled in a 1,148-page document that the EU had violated WTO rules by the undue delay in the approval of GM products. The WTO also ruled that bans by Austria, Belgium, France, Germany, Italy, and Luxembourg violated WTO rules on a number of GM products despite the fact that the European Commission had approved the products as safe. The EU decided not to appeal against the ruling partly because the EU has put in place its own precautionary system and has approved the import of nine GM products since 2004. The nine EU-approved GM varieties include herbicide-tolerant and insect-resistant maize (developed by Monsanto, Pioneer Hi-Bred, and Syngenta), two herbicide-tolerant maize (by Bayer and Monsanto), one insect-resistant maize (by Monsanto), an herbicide-tolerant soya bean (by Monsanto), and an herbicide-tolerant sugar beet (by Monsanto). However, approvals for cultivation still remain highly restricted and only one variety of pest-resistant maize (developed by Monsanto) has been cleared for production. As of March 2008, there were 18 GM varieties waiting for cultivation approval in the EU and another 50 (mainly maize and soyabean) awaiting import clearance for use in food and animal feed.

they could otherwise. The issue of labeling is complex, however, because labeling could also be used to describe the benefits of GM foods, and some would argue that markets perform better when consumers are informed. Anderson pointed to the WTO process as important for reducing trade distortions and improving how natural resources are better used to produce food and fiber.

Protecting Proprietary Research

Intellectual property (IP) rights affect the ability of public-sector and private-sector researchers to conduct innovative research in agriculture and protect the transfer of knowledge and technology. From the perspective of some workshop participants, IP rights have recently come to be seen as a major barrier to the advancement of agricultural biotechnologies. The opportunities and challenges of IP and proprietary science include issues related to ownership, access, economic benefit, and national sovereignty.

Intellectual Property Institutions

In the past century, a battery of legal instruments have been used to protect IP, but these were of little direct relevance for public-sector and nonprofit scientists. Agricultural research information was openly accessible to all: germplasm was pooled in gene banks by countries around the world, and collaboration and free exchange of cultivars occurred between research centers in developed countries, such as the United States, gene banks in international agricultural research centers, and users in international agricultural research systems worldwide. As Brian Wright, of the University of California at Berkeley, pointed out, farmers also contributed freely to the pool of agricultural technology—nearly all mechanical innovations in the United States came from farmers and blacksmiths who did not patent any of their innovations.

The current IP framework has changed substantially since 1980. The University and Small Business Patent Procedures Act of 1980 (the Bayh-Dole Act) provided a U.S. legal framework for technologies developed with public money to be licensed out from the public to the private sector and encouraged researchers to transfer their technologies into the marketplace. Decisions of the U.S. Patent and Trademark Office allowed U.S. researchers to patent life forms, which included not only plants but the constituents of plants, genes, and bacteria. A major revolution in the worldwide exchange of IP followed soon after and brought about the signing of the Agreement on Trade-Related Aspects of Intellectual Property Rights (the TRIPS Agreement) in 1994 (see Box 3-3).

Box 3-3
The Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS)

The TRIPS agreement is an international treaty negotiated in 1994 that sets minimum standards for most forms of intellectual property (IP) regulation in all member countries of the World Trade Organization (WTO). Of importance to biotechnology developments, the TRIPS agreement deals with copyright and related rights; patents, including the protection of new varieties of plants; trademarks; undisclosed or confidential information, including trade secrets and test data; and specified enforcement procedures, remedies, and dispute resolution procedures.

The significance of the TRIPS agreement is that it narrows the global gap in how IP is protected and moves the protections under a common international framework. It establishes minimum levels of IP protection for governments to provide fellow WTO members. IP protection encourages creation and invention, especially in the period after the protection expires and creations and inventions enter the public domain. The TRIPS agreement itself introduced IP law into the international trading system for the first time, and it remains the most comprehensive international agreement on intellectual property.

The agreement highlighted another principle: that IP protection should lead to innovation and technology transfer, that such protection would benefit producers and users, and that it would enhance economic and social welfare. Developing countries in particular see technology transfer as a great benefit to protect IP rights. The TRIPS agreement includes a number of important provisions, such as one that requires governments in developed countries to provide incentives for companies to transfer technology to least-developed countries.

Although the TRIPS obligations apply equally to all member states, developing countries were provided more time to implement applicable changes in their national laws. The TRIPS agreement took effect on January 1, 1995, and developed countries were given 1 year to ensure that their laws and practices conformed to the agreement. Developing countries and transition economies (under specified conditions) were given 5 years, until 2000; and least-developed countries had 11 years, until 2006.

SOURCE: WTO, 2008.

IP rights protections in developing countries are too weak to provide much incentive for private companies to transfer technology or research to parties in those countries, Pray asserted, because they cannot be assured that other companies in the country will be prohibited from capitalizing on their inventions without fair compensation. If technologies cannot be protected, there is a disincentive to investing in developing them further. For investigators who want to develop products that can benefit the developing world, an important consideration is where to patent a new technology. Although the TRIPS agreement requires countries to develop IP protections that innovators can apply for, patents are granted by individual nations. There is no "international" patent that applies worldwide. Thus the desired outcome by Richard Meagher's research group when it discovered how to control the electrochemical state of arsenic was that companies in the industrialized world would license the technology and develop it further. However, the group also wanted it to be freely available for use in India, where arsenic poisoning is a severe problem. To accomplish those goals, the group applied for patents in the United States but not in India: if it had not applied for patents in the United States, few companies would have stepped forward to invest in improving the technology.

A similar approach was taken in the development of vitamin A–enriched golden rice; material transfer agreements were used to obtain permissions and to incorporate dozens of patents owned by several parties. The patents were not filed in places like Bangladesh, so the rice can be freely used and improved in that country where many people suffer from vitamin A deficiency.

Yet Wright worried that future IP rights agreements might make it more difficult to allow such tailored arrangements to proceed so that the public sector, nonprofit organizations, or companies in poor countries can have the confidence to use an innovation without worrying about infringement. The UN World Intellectual Property Organization has been working on a Substantive Patent Law Treaty that would institute a worldwide patent system modeled on U.S. patent criteria and management. He encouraged representatives of developing countries to follow the discussions closely.

Protection of Public-Sector and Collaborative Research

The fact that IP regimes are not robust in developing countries may adversely affect public-sector researchers in those countries. Although IP rights exist to protect artisan discoveries, such as cooking or plowing improvements, discoveries in biology are generally outside the scope of such protection. When public researchers in developing countries collaborate with overseas researchers, it is likely that patentable inventions flowing from the collaboration are protected under an industrialized country's IP regime. Developing country investigators might not be aware that because they are co-inventors, their names should be included on patent filings.

Majiwa recalled a Kenyan scientist who collaborated with U.S. scientists on the biological aspects of extremophiles only to find later that enzymes from the microorganisms, which came from Kenya, were being used in laundry detergents for commercial profit in the U.S. market. No benefits accrued to the African collaborator or to his country, and the purported exploitation made national headlines in Kenya. Majiwa suggested that Africans are discouraged from engaging in research at all because IP protections for innovations that might come out of their research are lacking in their own countries, and they are worried that patents on research innovations they have worked on locally may have already been filed by others elsewhere.

The existence of very strong IP protections in the United States is hurting public-sector innovation in agricultural biotechnology, according to Wright. That is due in part to the nature of genetically engineered seeds, which are essentially "little carriers" of attributes that have been built on by many innovators. IP related to those attributes accumulates, and each time someone wants to add an attribute, all the other technologies inherent in that seed "package" must be licensed. In Wright's view, the costs of licensing and disputes over patents have so slowed the progress of research that they are among the factors driving the consolidation of seed companies to the point where now only a few major players are involved in engineering new crops.

That reality is hurting public-sector investigators, who may be freed to work on the seed packages in the laboratory but are at a disadvantage when the time comes to negotiate with the package owners about commercializing the improvements they have made. Moreover, the protectiveness over IP is spilling over into the public sector. At a time when the world is looking to the public sector to develop innovations in orphan crops and take the technology to the developing world, the public sector is finding itself with more responsibility but less freedom to operate.

Intellectual Property May Not Be as Much of a Barrier for Developing Countries

Many workshop participants felt that IP barriers could be overcome because companies like DuPont, as Kishore pointed out, have been willing to make IP available to others, especially when it was related to subsistence farming.

Juma suggested that countries that have been able to industrialize quickly have relied on tapping into technologies that are now in the public domain because their patent terms have expired. "One of the reasons they are developing so fast is that they are harvesting publicly available knowledge that they don't have to pay for. And when they come closer to the cutting edge, they are forced to start inventing. By that time, they have accumulated enough capital to pay for the inventive activities."

Workshop participants were encouraged by the existence of nonprofit organizations that provide access to IP rights and benefit agricultural researchers in the public sector who otherwise would not have the means to obtain the rights to IP (see Box 3-4).

CHALLENGE 7: ANTICIPATING FUTURE NEEDS AND DIRECTIONS

Researchers and decision-makers need to anticipate changes that will affect agricultural production and consumer demand.

Climate Change

Although climate models are evolving, there is a considerable degree of uncertainty in predicting the future climate of Africa and south Asia and, by association, the environment for farming in the future. Extreme weather events seem likely, but their pattern and extent are not fully understood. Agricultural planners need the help of cross-disciplinary tools to predict how global climate change will affect the natural resource base of farming. Remote-sensing technology, which uses imaging instruments mounted on satellites or aircraft, can provide a record of changes in a region, including the locations of human settlements, vegetation, and rainfall. The images can be used to examine environmental trends and human, agricultural, and environmental interactions, including the movement of plant and animal diseases. Such information may ultimately help nations to better understand the characteristics needed in crops and animals in a changing world.

Increased Meat Demand

As the developing world reaches greater levels of food security and wealth, population growth and rapid income growth leading to changes in lifestyle will increase demands for meat (Delgado et al., 1999). The developing world's population is projected to reach 3.4 billion by 2020, and its demand for meat is projected to increase by 2.8 percent a year from 1993 to 2020 (Pinstrup-Andersen et al., 1999; Pinstrup-Andersen,

Box 3-4
Organizations that Promote Access to Research and Transfer Technology

Several initiatives have been developed to bridge proprietary information and public research. Three such efforts were highlighted in the workshop: the Public Intellectual Property Resource for Agriculture (PIPRA), the Biological Innovation for Open Society (BiOS), and the African Agricultural Technology Foundation (AATF).

Public Intellectual Property Resource for Agriculture

PIPRA (http://www.pipra.org) is a nonprofit entity based at the University of California, Davis, that supports agricultural innovation for humanitarian and small-scale commercial purposes. Members include over 40 universities, public agencies, and nonprofit institutions. PIPRA helps innovators in developing countries to gain access to new agricultural technologies by educating farmers and scientists on international IP law and development and by providing a network to create licensing and material transfer agreements with its members.

Biological Innovation for Open Society

BiOS (http://www.bios.net) is a relatively new Australian-based effort that helps disadvantaged communities to develop new innovation systems for disadvantaged communities by applying the open-source idea to modern biotechnology research. The goal of BiOS is to enable innovations by fostering a protected commons of biotechnologies that is freely available to the worldwide research community under the terms of an open-source–based license. If BiOS can develop the right kinds of technologies, plant researchers and breeders throughout the world would gain greater access to information.

African Agricultural Technology Foundation

The AATF (http://www.aatf-africa.org) is a not-for-profit organization designed to facilitate and promote public-private partnerships for the access and delivery of appropriate proprietary agricultural technologies for use by resource-poor small-holder farmers in sub-Saharan Africa. AATF engages in technology scoping, interaction with technology developers, and negotiation. It keeps abreast of the latest information about agricultural production constraints and priorities in Africa and is familiar with major national, regional, and Africa-wide policies on agricultural development. AATF devotes the majority of its attention to proven technologies rather than those in the concept stage.

SOURCE: AATF, 2008; BiOS, 2008; PIPRA, 2008.

2000). However, many developing countries may not be able to meet the demand for meat, given current animal-husbandry practices and constraints (such as animal diseases and malnutrition) that make increased livestock production unsustainable. Biotechnology might be able to have a considerable effect on livestock production by improving the genetics, health, and nutrition of food animals.

An alternative solution, according to Kishore, would be to promote vegetable protein instead of animal protein. In his view, changing the world's eating habits could enable agricultural systems to conserve natural resources better. Vegetable proteins are superior to poultry, beef, and pork in energy input requirements, protein output relative to land use, and labor requirements. For example, soy is a good source of protein and is also a legume that improves soil quality and could help to increase the sustainability of agricultural resources. If the protein consumption of the developing world continues as projected and matches that of developed countries, soy and other vegetable proteins will need to be explored to create sustainable farming systems.

CLOSING THOUGHTS

Many discussions and debates about the use of agricultural biotechnology focus on whether its use brings greater benefits than risks to society. There have been fewer reflections from the perspective of what agricultural biotechnology can do to help developing countries, and it did not take long for the workshop participants to highlight the fact that technology does not exist in a vacuum. Agricultural biotechnology is only one of many potential tools in a complex package of solutions for economic development. Understanding how to build systems that can guide and manage the use of this relatively new technology to benefit developing countries became a central theme of the workshop.

Calestous Juma, who chaired the workshop's steering committee, expressed hope in his welcoming remarks that the workshop might pave the way for a better understanding of how society perceives new technologies and the factors that play into its adoption. Society is quick to consider the immediate safety questions for the environment and human health, but he argued that we need more venues for examining perceptions of risk, the socioeconomic consequences of new technologies, and policies and processes that encourage adoption and acceptance of technology and trust in it.

The participants in the workshop, who came from both developed and developing countries, contributed a rich set of perspectives to the examination of those issues. Many *potential* benefits of new agricultural biotechnologies were outlined during the course of the workshop, but it will be a critical exercise that will need to meet many objectives associated with setting priorities for the allocation of resources. There will be many entities playing active roles in addressing those priorities, and global partnerships will be a key part enabling the new technologies to move forward in ways that help developing countries.

References

AATF (African Agricultural Technology Foundation). 2008. African Agricultural Technology Foundation website. Available online at http://www.aatf-africa.org/ [accessed February 21, 2008].

Arntzen, C.J. 1997a. Edible vaccines. *Public Health Reports* 112:190-197.

Arntzen, C.J. 1997b. High-tech herbal medicine: Plant-based vaccines. *Nature Biotechnology* 15:221-222.

BiOS. 2008. BiOS website. Available online at http://www.bios.net [accessed February 21, 2008].

Bouis, H.E. 2002. Plant breeding: A new tool for fighting micronutrient malnutrition. *Journal of Nutrition* 132:491S-494S.

Cartagena Protocol. 2008. Background: Cartagena Protocol. United Nations Environment Programme. Available online at http://www.cbd.int/biosafety/background.shtml [accessed February 28, 2008].

CBD (Convention on Biological Diversity). 2008. Convention on Biological Diversity. United Nations Environment Programme. Available online at http://www.cbd.int/convention/ [accessed February 28, 2008].

Coghlan, A. 2005. Potato-based vaccine success comes too late. February 14. *New Scientist*. Available online at http://www.newscientist.com/article.ns?id=dn7006 [accessed April 21, 2008].

Dargie, J. 2001. Biotechnology, GMOs, Ethics, and Food Production. Food and Agriculture Organization of the United Nations. Available online at http://www.fao.org/news/2001/stockholm/biotech.pdf [accessed March 6, 2008].

Delgado, C., M. Rosegrant, H. Steinfeld, S. Ehui, and C. Courbois. 1999. Livestock to 2020: The Next Food Revolution, 2020 Vision for Food, Agriculture, and the Environment. Discussion Paper 28. Washington, DC: International Food Policy Research Institute.

Doering, D.S., A. Cassara, C. Layke, J. Ranganathan, C. Revenga, D. Tunstall, and W. Vanasselt. 2002. Tomorrow's Markets: Global Trends and Their Implications for Business. A Collaboration of World Resources Institute, United Nations Environment Programme, World Business Council for Sustainable Development. Available online at http://archive.wri.org/publication_detail.cfm?pubid=3155 [accessed March 6, 2008].

EIA (Energy Information Administration). 2003. International Energy Outlook 2003. U.S. Department of Energy, Office of Integrated Analysis and Forecasting. Available online at http://tonto.eia.doe.gov/ftproot/forecasting/0484(2003).pdf [accessed March 10, 2008].

FAO (Food and Agriculture Organization of the United Nations). 2000. FAO Stresses Potential of Biotechnology but Calls for Caution. Press Release 00/17. Food and Agriculture Organization of the United Nations. Available online at http://www.fao.org/WAICENT/OIS/PRESS_NE/PRESSENG/2000/pren0017.htm [accessed March 6, 2008].

FAO. 2006a. Livestock a Major Threat to Environment: Remedies Urgently Needed. Food and Agriculture Organization of the United Nations. November 29. Available online at http://www.fao.org/newsroom/en/news/2006/1000448/ [accessed March 10, 2008].

FAO. 2006b. FAO's Role in Biosafety within a Biosecurity Framework: Scope and Relevance of "Biosafety" as a Contribution to Sustainable Agriculture and Food Production. 28 February–3 March. Rome: Food and Agriculture Organization of the United Nations.

FAO. 2007. FAO Biosecurity Toolkit. Food and Agriculture Organization of the United Nations. Available online at http://www.fao.org/docrep/010/a1140e/a1140e00.htm [accessed March 24, 2008].

Gaugitsch, H. 2002. Scientific Aspects of the Biosafety Debate. Pp. 83-91 in The Cartagena Protocol on Biosafety: Reconciling Trade and Biotechnology with Environment and Development. C. Bail, R. Falkner, and H. Marquard, eds. London, UK: Earthscan Publishing and Royal Institute of International Affairs.

GEF (Global Environmental Facility). 2003. What Kind of World? The Challenge of Land Degradation. Washington, DC: Global Environmental Facility. Available online at http://www.gefweb.org/Outreach/outreach-PUblications/2003landdegradation-EN.pdf [accessed March 6, 2008].

GMOERA (GMO Environmental Risk Assessment). 2008. International Project on GMO Environmental Risk Assessment Methodologies. Available online at http://www.gmoera.umn.edu [accessed March 20, 2008].

Graham, S. 2000. Plant-derived biologics meeting (Transcript). April 6. Ames, IA. Pp. 88-89. Available online at http://www.fda.gov/cber/minutes/plnt2040600.pdf [accessed April 21, 2008].

Guerinot, M.L. 2000. The green revolution strikes gold. *Science* 287(5451):241-243.

Gupta, A. 2000. Governing trade in genetically modified organisms: The Cartagena Protocol on biosafety. *Environment* 42(4):22-33.

Harada, M., J. Nakanishi, E. Yasoda, M.C. Pinheiro, T. Oikawa, G. de Assis Guimaras, B. da Silva Cardoso, T. Kizaki, and H. Ohno. 2001. Mercury pollution in the Tapajos River Basin, Amazon: Mercury level of head hair and health effects. *Environment International* 27(4):285-290.

HarvestPlus. 2008. HarvestPlus: Breeding Crops for Better Nutrition. Available online at http://www.harvestplus.org/ [accessed March 7, 2008].

Holden, C. 2006. African soil exhaustion. *Science* 312:31.

ISAAA (International Service for the Acquisition of Agri-Biotech Applications). 2008. Global Status of Commercialized Biotech/GM Crops: 2007. Ithaca, NY: International Service for the Acquisition of Agri-biotech Applications. Available online at http://www.isaaa.org/resources/publications/briefs/37/executivesummary/default.html [accessed March 24, 2008].

InterAcademy Council. 2004. Realizing the Promise and Potential of African Agriculture. Amsterdam, The Netherlands: Royal Netherlands Academy of Arts and Sciences.

IRRI (International Rice Research Institute). 2008. Weedy Rice Attacks Asia's Direct-seeded Rice. Available online at http://www.irri.org/irrc/streams/weedy%20rice.asp [accessed March 10, 2008].

Lal, R., M. Griffin, J. Apt, L. Lave, and M.G. Morgan. 2004. Managing soil carbon. *Science* 304:393.

The Micronutrient Initiative. 2008. The Micronutrient Initiative. Available online at www.micronutrient.org [accessed March 7, 2008].

NRC (National Research Council). 1999. Perspectives on Biodiversity. Washington, DC: National Academy Press.

NRC. 2002a. Animal Biotechnology: Science-based Concerns. Washington, DC: The National Academies Press.

NRC. 2002b. Knowledge and Diplomacy: Science Advice in the United Nations System. Washington, DC: The National Academies Press.

Pinstrup-Andersen, P. 2000. The future world food situation and the role of plant diseases. *Canadian Journal of Plant Pathology* 22:321-331.

Pinstrup-Andersen, P., R. Pandya-Lorch, and M.W. Rosegrant. 1999. World Food Prospects: Critical Issues for the Early Twenty-first Century. Washington, DC: International Food Policy Research Institute (IFPRI).

PIPRA (Public Intellectual Property Resource for Agriculture). 2008. Public Intellectual Property Resource for Agriculture website. Available online at http://www.pipra.org [accessed February 21, 2008].

Pollack, A. 2003. Grant Aims at More Healthful Crops. New York Times. October 21.

Prasanna, B.M., S.K. Vasal, B. Kassahun, and N.N. Singh. 2001. Quality protein maize. *Current Science* 81(10):1308-1319.

Robertson, G.P., E. A. Paul, and R.R. Harwood. 2000. Greenhouse gases in intensive agriculture: Contributions of individual gases to the radiative forcing of the atmosphere. *Science* 289:1922-1925.

Shah, M., and M. Strong. 1999. Food in the 21st Century: From Science to Sustainable Agriculture. Washington, DC: CGIAR System Review Secretariat. Available online at http://www.worldbank.org/html/cgiar/publications/shahbook/shahbook.pdf [accessed March 6, 2008].

Susskind, L.E. 1994. Environmental Diplomacy: Negotiating More Effective Global Agreements. New York, NY and Oxford, UK: Oxford University Press.

Tilman, D., J. Fargione, B. Wolff, C. D'Antonio, A. Dobson, R. Howarth, D. Schindler, W.H. Schlesinger, D. Simberloff, and D. Swackhamer. 2001. Forecasting agricultural driven global environmental change. *Science* 292:281-284.

Toenniessen, G.H. 2002. Crop genetic improvement for enhanced human nutrition. *Journal of Nutrition* 132:2493S-2946S.

Tripurani, S.K., N.S. Reddy, and K.R.S. Sambasiva Rao. 2003. Green revolution vaccines, edible vaccines. *African Journal of Biotechnology* 2(12):679-683.

UNESCO (United Nations Education, Scientific, and Cultural Organization). 2008. Arsenic Filter Stalks Silent Killer in Bangladesh. Available online at www.unesco-ihe.org/content/download/1574/17059/file/Arsenic_science%20article%201%20Dec.doc [accessed March 10, 2008].

UNFPA (United Nations Population Fund). 2002. Water and Population. Chapter 2 Environmental Trends, in The State of World Population 2001. Available online at http://www.unfpa.org/swp/2001/english/ch02.html [accessed March 6, 2008].

United Nations. 2007. World Population Prospects: The 2006 Revision. New York, NY: United Nations Department of Economic and Social Affairs. Available online at http://www.un.org/esa/population/publications/wpp2006/wpp2006.htm [accessed March 6, 2008].

Veiga, M.M. 1997. Mercury in Artisanal Gold Mining in Latin America: Facts, Fantasies, and Solutions. UNIDO–Expert Group Meeting–Introducing New Technology for Abatement of Global Mercury Pollution Deriving from Artisanal Gold Mining, Vienna, July 1-3. Available online at http://www.facome.uqam.ca/pdf/veiga_02.pdf [accessed March 10, 2008].

WHO (World Health Organization). 1995. Global prevalence of vitamin A deficiency: Micronutrient deficiency information system working paper No. 2. Available online at http://www.who.int/nutrition/publications/vad_preface.pdf [accessed April 14, 2008].

WHO. 1998. World Health Report 1998 Press Kit: 50 Facts from the Report. Available online at http://www.who.int/whr/1998/media_centre/en/ [accessed March 7, 2008].

World Bank. 2008. World Development Report: Agriculture for Development. Available online at www.worldbank.org/wdr2008 [accessed March 7, 2008].

WTO (World Trade Organization). 2008. TRIPS Material on the WTO website: Information on Intellectual Property in the WTO, News and Official Records of the Activities of the TRIPS Council, and Details of the WTO's Work with Other International Organizations in the Field. Available online at http://www.wto.org/english/tratop_e/trips_e/trips_e.htm [accessed February 7, 2008].

Ye, X., S. Al-Babili, A. Kloti, J. Zhang, P. Lucca, P. Beyer, and I. Potrykus. 2000. Engineering the provitamin A (β-carotene) biosynthetic pathway into (carotenoid-free) rice endosperm. *Science* 287 (5451):303-305.

Zheng, F.-L., S.D. Merrill, C.-H. Huang, D.L. Tanaka, F. Darboux, M.A. Liebig, and A.D. Halvorson. 2004. Runoff, soil erosion, and erodibility of conservation reserve program land under crop and hay production. *Soil Science Society of America Journal* 68:1332-1341.

Appendix A

Steering Committee Biosketches

Calestous Juma, *Chair,* is professor of the practice of international development and director of the Science, Technology, and Globalization Project at the Harvard University Kennedy School of Government and McCluskey Fellow at the Yale University School of Forestry and Environmental Studies. He is a former executive secretary of the UN Convention on Biological Diversity and founding director of the African Centre for Technology Studies in Nairobi, and he served as chancellor of the University of Guyana. Dr. Juma cochaired the African High-Level Panel on Modern Biotechnology of the African Union and serves as a special adviser to the International Whaling Commission. He is lead author of *Innovation: Applying Knowledge in Development* and *Freedom to Innovate: Biotechnology in Africa's Development*. He has been elected to several scientific academies, including the Royal Society of London, the U.S. National Academy of Sciences, the Academy of Sciences for the Developing World (TWAS), the UK Royal Academy of Engineering, and the African Academy of Sciences. He holds a DPhil in science and technology policy studies and has received numerous international awards and honorary degrees for his work on sustainable development. He is the editor of the *International Journal of Technology and Globalisation* and the *International Journal of Biotechnology.*

Edward (Ned) Groth III is retired as senior scientist at Consumers Union (CU). His responsibilities included directing major science-policy projects on U.S. pesticide regulation and international food safety standard-setting. Dr. Groth formerly directed the Public Service Projects Department in

CU's Technical Division. In that capacity, he oversaw evaluations of the health and environmental implications of products; coordinated technical input on food safety, risk communication, and related topics to the editors of *Consumer Reports* and other CU publications; and coordinated technical support of advocacy work on a similar array of issues. He is coauthor of the book *Pest Management at the Crossroads* (Consumers Union, 1996) and several more recent technical reports analyzing risks associated with pesticide residues in foods. Test projects he has directed in recent years include investigations of plastic components that migrate from food containers into foods and a national survey of lead concentrations in drinking-water supplies. Dr. Groth has been a member of the Food Forum of the National Academy of Sciences, of an Environmental Protection Agency advisory committee on managing multiple exposures to lead, of the Steering Committee of the Children's Environmental Health Network, and of a Joint Food and Agriculture Organization–World Health Organization Expert Consultation on Risk Communication in Food Safety. He holds an AB in biology from Princeton University (1966) and a PhD in biological sciences from Stanford University (1973).

Richard R. Harwood has been the C.S. Mott Chair of Sustainable Agriculture at Michigan State University since 1990. Dr. Harwood's recent work has focused on research, extension, and teaching in production ecology as a foundation for sustainable agriculture. His work on the biogeochemistry of soil carbon and nitrogen has been widely published. He serves on the Interim Science Council of the Consultative Group for International Agricultural Research and has served on the Board on Agriculture and Natural Resources. Dr. Harwood was trained in horticultural genetics and plant breeding and has degrees from Cornell University and Michigan State University. He worked as a plant breeder and production agronomist with the Rockefeller Foundation in Asia from 1967 to 1976. He was director of the Rodale Research Center in organic agriculture from 1977 until 1985, when he became director of Asian programs with Winrock International.

Luis Herrera-Estrella is director of the Plant Biology Unit at the Center for Research and Advanced Studies of the National Polytechnic Institute in Irapuato, Mexico. His expertise is in plant molecular biology. His recent research has addressed the cellular and molecular mechanisms that regulate root development in response to nutrient availability and the physiology and genetics of the *Arabidopsis* response to phosphate availability. Dr. Herrera-Estrella has received numerous awards for his work, including the Javed Husain Award from the UN Educational, Scientific, and Cultural Organization in 1987, the Award in Biology from the Third World Academy of Sciences in 1994, the RedBio Medal from the Latin American Biotechnology Network in 1998, and the WIPO Medal from the World Intellectual Property Organization in 2000. He recently developed a technology to produce aluminum-resistant transgenic plants based on the modification of the production of organic acids. He has published over 80 peer-reviewed articles in internationally recognized journals. Dr. Herrera-Estrella was elected to the National Academy of Sciences in 2003.

Barbara A. Schaal is a professor of biology and genetics in the Department of Biology at Washington University in St. Louis. She was elected to the National Academy of Sciences in 1999 for her investigations in the evolution of plant populations. Her work on the application of DNA analysis to plant evolution at the population level showed an unexpectedly high level of diversity due to limited gene migration. Her research includes the use of gene genealogies and coalescence theory to detect geographic patterns of gene migration between populations of North American native plants. She also conducts studies on species relationships in plants native to South America, Africa, and Asia and on issues related to the conservation of rare plants. Her current work examines gene flow and genetic diversity in wild and cultivated Asian rice. Dr. Schaal chaired Washington University's Department of Biology from 1993 to 1997 and has been chair of the Scientific Advisory Council for the Center for Plant Conservation, president of the Society for the Study of Evolution, associate editor of *Molecular Biology and Evolution*, and president of the Botanical Society of America. She received her PhD in population biology from Yale University in 1974.

Greg Traxler is a professor in the Department of Agricultural Economics and Rural Sociology at Auburn University. He has expertise in the economics of biotechnology innovation. His research interests include the process and effects of agricultural research, the economics of intellectual-property rights, the distribution of benefits of biotechnology innovation, and the coordination of public-sector and private-sector agricultural research. Dr. Traxler has published papers on the economics of biotechnology innovation in poor nations, including genetically engineered soybeans in Argentina and transgenic cotton in Mexico, and on the valuation of pre-commercial germplasm. He also has presented before National Research Council committees on such topics as pesticide use in *Bt* cotton, economic incentives in genetic improvement research, and the economic context of agricultural biotechnology in developing countries. Dr. Traxler holds a PhD in agricultural economics from Iowa State University.

José A. Zaglul is president of EARTH University in San José, Costa Rica. He has expertise in international agricultural research and education. Since 1989, Dr. Zaglul has presided over EARTH University, a private, international nonprofit university dedicated to the conservation and sustainable development of the humid tropics. Previously, he served as head of the Animal Production Department of the Centro Agrícola Tropical de Investigación y Enseñanza (CATIE) in Costa Rica. Dr. Zaglul was professor of food science and then vice president of research and extension of the Instituto Tecnológico de Costa Rica (ITCR). Dr. Zaglul has extensive knowledge of international conflict resolution and participated in a conference organized by Georgetown University on conflict resolution at the Mediterranean Agricultural Institute of Chania, Greece, in 2002. His professional interests include the sustainable management of natural resources and its relationship to food production. Dr. Zaglul has presented numerous publications and papers and participates in numerous professional conferences annually, such as the Global Consortium for Higher Education and Research in Agriculture's 2003 annual meeting, for which he serves as president-elect. He earned a PhD in meat and muscle biology from the University of Florida.

Appendix B

Workshop Agenda

GLOBAL CHALLENGES FOR GUIDING AND MANAGING BIOLOGICAL TECHNOLOGIES

AGENDA

October 25, 2004

8:30 a.m.	Welcome and Introductory Remarks Calestous Juma, Chair, Steering Committee
SESSION I:	Opportunities to Improve Agricultural Production: Coping with Challenges of Abiotic and Biotic Stresses
9:00	Lead Speaker: Bongiwe Njobe, Department of Agriculture, South Africa
9:30	Panel Discussion John Lynam, Rockefeller Foundation, Nairobi, Kenya Phelix A. O. Majiwa, African Agricultural Technology Foundation, Nairobi, Kenya Suman Sahai, Gene Campaign, New Dehli, India
10:15	Break

10:45	Moderated General Dialogue Moderator: Don Doering, Winrock International
12:00	Lunch
SESSION II:	Opportunities to Improve Food Security and Human Nutrition: Coping with Challenges of Human Health
1:30	Lead Speaker: Ganesh Kishore, Dupont Agriculture and Nutrition, St. Louis, Missouri
2:00	Panel Discussion Rebecca Nelson, Cornell University, Ithaca, New York Benjavan Rerkasem, Chiang Mai University, Chiang Mai, Thailand Mariam Sticklen, Michigan State University, East Lansing, Michigan
2:45	Break
3:15	Moderated General Dialogue Moderator: Gregory Jaffe, Center for Science in the Public Interest
4:30	Wrap up and Overview of Day 2 of the Workshop Calestous Juma, Chair, Steering Committee
5:00	Adjourn
5:00–7:00	Reception and Social Hour

October 26, 2004

8:30 a.m.	Opening Remarks Calestous Juma, Chair, Steering Committee
SESSION III:	Opportunities to Preserve and Protect Biodiversity and Enhance Conservation of Natural Resources: Coping with Natural Resource Use and Effects
8:45	Lead Speaker: Luiz J.C.B. Carvalho, CENARGEN-EMBRAPA, Brazil

9:15	Panel Discussion Kym Anderson, The World Bank, Washington, DC David Andow, University of Minnesota, St. Paul Richard Meagher, University of Georgia, Athens Harald Schmidt, The Nuffield Council on Bioethics, London, England
10:00	Break
10:30	Moderated General Dialogue Moderator: Daniel Karanja, Partnership to Cut Hunger and Poverty in Africa
11:45	Lunch
SESSION IV:	Innovation Systems: Coping with the Needs of the Developing World
1:00	Lead Speaker: Brian Wright, University of California, Berkeley
1:30	Panel Discussion Carl Pray, Rutgers University, New Brunswick, New Jersey Piet van der Meer, HORIZONS *sprl*, Belgium
2:15	Moderated General Dialogue Moderator: June Blalock, USDA, Agricultural Research Service
3:30	Break
4:00	Synthesis of Workshop Discussions: Key Findings Synthesizer: Anne Courtney Radcliff, The Pew Initiative on Food and Biotechnology
5:00	Closing Remarks Calestous Juma, Chair, Steering Committee
5:30	Adjourn

Appendix C

List of Workshop Participants

Kym Anderson, World Bank
David Andow, University of Minnesota
Pedro Antonio Arraes Pereira, EMBRAPA/LABEX/ARS/USDA
Jeffrey Barach, National Food Processors Association
June Blalock, U.S. Department of Agriculture, Agricultural Research Service
Jack Bobo, U.S. Department of State
Richard Brenner, U.S. Department of Agriculture, Agricultural Research Service
Kim Brooks, The Pew Initiative on Food and Biotechnology
Luiz J.C.B. Carvalho, EMBRAPA
Margriet Caswell, U.S. Department of Agriculture, Economic Research Service
Anthony Cavalieri, Center for Strategic and International Studies
Steven Clapp, CRC Press LLC (FCN Publishing)
Wanda Collins, U.S. Department of Agriculture, Agricultural Research Service
Don Doering, Winrock International
Joseph Dudley, INTELLIBRIDGE
Terri Dunahay, U.S. Department of Agriculture, Animal and Plant Health Inspection Service
Marsha Echols, Howard University School of Law
Sylvia Fallon, U.S. Environmental Protection Agency
Robert Federick, U.S. Environmental Protection Agency

Lindsey Fransen, World Resources Institute/IGP
Jeff Fritz, DuPont
Sakiko Fukuda-Parr, Harvard University
Harvey Glick, Monsanto Company
Indur Goklany, U.S. Department of the Interior
Jean Halloran, Consumer Policy Institute/Consumers Union
Debora Hamernik, U.S. Department of Agriculture, Cooperative State Research, Education, and Extension Service
Kenneth Haymes, U.S. Environmental Protection Agency
Neil Hoffman, Biotechnology Regulatory Services
Lindsay Holloman, Georgetown University
Gregory Jaffe, Center for Science in the Public Interest
Julian Jahta, Department of Agriculture, South Africa
Daniel Jones, U.S. Department of Agriculture, Cooperative State Research, Education, and Extension Service
Daniel Karanja, Partnership to Cut Hunger and Poverty in Africa
John Kelmelis, U.S. Department of State
Rarvi Khush, U.S. Department of State
John King, U.S. Department of Agriculture, Economic Research Service
Ganesh Kishore, DuPont Agriculture and Nutrition
Melissa Kramer, U.S. Environmental Protection Agency
John Lynam, Rockefeller Foundation
Bruce MacBryde, U.S. Department of Agriculture, Animal and Plant Health Inspection Service
Phelix A.O. Majiwa, African Agricultural Technology Foundation
Ved Malik, U.S. Department of Agriculture, Animal and Plant Health Inspection Service
Sally McCammon, U.S. Department of Agriculture, Animal and Plant Health Inspection Service
Kathryn McConnell, U.S. Department of State
Zak McLain, Eversole Associates
Richard Meagher, University of Georgia
Terry Medley, DuPont Company
Siphiwe Mkhize, South African Embassy
Rebecca Nelson, Cornell University
T. Clint Nesbitt, U.S. Department of Agriculture, Animal and Plant Health Inspection Service
Bongiwe Njobe, Department of Agriculture, South Africa
Maria Oria, Institute of Medicine
Daisy Pistey-Lyhne, American Society of Agronomy
Diahanna Post, Brookings Institution
Kerry-Ann Powell, U.S. Public Interest Research Group
Carl Pray, Rutgers University

Anne Courtney Radcliff, The Pew Initiative on Food and Biotechnology
Donna Ramaekerzahn, Pioneer Hi-Bred International, Inc.
Thomas Redick, Gallop, Johnson, & Newman, L.C.
Benjavan Rerkasem, Chiang Mai University, Thailand
Louisa Roberts, Meridian Institute
Suman Sahai, GENE CAMPAIGN
Peter Schmeissner, U.S. Department of Agriculture, Foreign Agricultural Service
Harald Schmidt, Nuffield Council on Bioethics, United Kingdom
Cynthia Schneider, Georgetown University
Kalidas Shetty, U.S. Department of State
Vlad Spanu, The Moldova Foundation
Madelyn Spirnak, U.S. Department of State
Mariam Sticklen, Michigan State University
Ann Thro, U.S. Department of Agriculture, Cooperative State Research, Education, and Extension Service
Piet van der Meer, HORIZONS *sprl*
Tom Vestal, Texas A&M University
Harrison Wein, National Institutes of Health
Brian Wright, University of California, Berkeley
Mayuko Yamamoto, World Bank