

**AGRICULTURAL BIOTECHNOLOGY,
POVERTY REDUCTION,
AND
FOOD SECURITY**

A Working Paper
May 2001

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FOREWORD

Recent breakthroughs in biotechnology have led to rapid progress in understanding the genetic basis of living organisms, and the ability to develop products and processes useful to human and animal health, food and agriculture, and industry. In agriculture, there is increasing use of biotechnology for genetic mapping and marker-assisted selection to aid more precise and rapid development of new strains of improved crops and livestock. Other biotechnology applications such as tissue culture and micropropagation are being used for the rapid multiplication of disease-free planting materials. New diagnostics and vaccines are being widely adopted for the diagnosis, prevention, and control of animal and fish diseases. Many of these developments have taken place mainly in the United States and other developed countries. But in recent years several developing countries in Asia including People's Republic of China, India, Indonesia, Malaysia, Pakistan, Philippines, and Viet Nam have begun to invest heavily in biotechnology.

Biotechnology has given us a new tool to improve food security and reduce poverty. This development is encouraging since the Green Revolution technologies, which have doubled food production and reduced poverty during the past three decades, have already run their course in much of Asia. Conventional breeding, widely used during the Green Revolution era, no longer provides needed breakthroughs in yield potentials, nor the solution to the complex problems of pests, diseases, and drought stress. That is particularly true in the rainfed areas where the poor are concentrated. The challenge is how to use new developments in biotechnology together with information technology and new ways of managing knowledge to make the complex agricultural systems of Asia more productive and sustainable.

The development of agricultural biotechnology is perceived by some as posing considerable risks to human health and the environment. Most of the debate on biotechnology has been focused on genetically modified organisms (GMOs). The public debate surrounding GMOs has heightened concerns that genetic engineering may in the long run be harmful to human health and the environment unless effective regulatory frameworks are implemented. Indeed, the public and private sectors must

manage the introduction and use of biotechnology to maximize benefits and minimize risks.

Given these developments, the Asian Development Bank (ADB), together with the Australian Centre for International Agricultural Research and the Australian Agency for International Development, undertook a study to examine the opportunities and risks of using biotechnology in reducing poverty and achieving food security in Asia. The study is designed to provide the latest information on the effective and safe use of biotechnology for the benefit of Asian farmers. As a premier development institution, ADB is responsible for assisting its developing member countries (DMCs) to deal with potential risks of biotechnology and providing information on various issues biotechnology relating.

The team effort used ADB staff, international experts, and an external review panel under the guidance of the Directors, Agriculture and Social Sectors Departments for Regions East and West. A working group made up of ADB staff reviewed the work of the international experts. A panel of external experts from international organizations was constituted to review and comment on the approach, methods, and results of the study.

The results and recommendations of the study were presented for comment at an international workshop held 15-17 January 2001 in Manila. Some 60 persons attended, including senior government officials and representatives of international agencies, nongovernment organizations, private sector companies, and funding agencies. The revised report is being published by ADB as a Working Paper to provide a basis for future discussion between ADB and its DMCs on how to use biotechnology safely and effectively to reduce poverty and increase food production in Asia. These findings and recommendations should prove useful to all concerned with improving the economic and social conditions of rural populations in Asia.

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ABBREVIATIONS

ACO	– 1-aminocyclopropane-1-carboxylic acid oxidase
AARD	– Agency for Agricultural Research and Development
ACIAR	– Australian Centre for International Agricultural Research
ADB	– Asian Development Bank
AFLP	– amplified fragment length polymorphism
AFMA	– Agriculture, Fisheries Modernization Act
AMBIONET	– Asian Maize Biotechnology Network
APEC	– Asia-Pacific Economic Cooperation
ARBN	– Asian Rice Biotechnology Network
ASEAN	– Association of Southeast Asian Nations
AusAID	– Australian Agency for International Development
BBPT	– Agency for Technology Assessment and Application (Jakarta)
BCC	– Biotechnology Cooperative Center
BGA	– blue green algae
BIOBIN	– OECD's BioTrack Online and UNIDO's BINAS
BIOTEC	– National Center for Genetic Engineering and Biotechnology (Thailand)
BIOTECH	– National Institute of Molecular Biology and Biotechnology (Philippines)
Bt	– <i>bacillus thuringiensis</i>
BW	– bacterial wilt
ccs	– commercial cane sugar
cDNA	– complementary DNA
CEMB	– Centre of Excellence in Molecular Biology
CEPT	– Common effective preferential tariff
CGIAR	– Consultative Group on International Agricultural Research
CIAT	– Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)
CIMMYT	– Centro Internacional de Mejoramiento de Maiz y Trigo (International Maize and Wheat Improvement Center)
CIP	– Centro Internacional de la Papa (International Potato Center)
CMV	– cucumber mosaic virus

COGENT	– Coconut Mejoramiento de Maiz y Trigo (International Maize and Wheat Improvement Center)
CSIR	– Council of Scientific and Industrial Research
DBT	– Department of Biotechnology (India)
DMC	– developing member country
DNA	– deoxyribonucleic acid
DOA	– Department of Agriculture
DST	– Department of Science and Technology (India)
EA	– executing agency
EBD	– infectious boval disease
FAO	– Food and Agriculture Organization
GATT	– General Agreement on Tariffs and Trade
GE	– genetically engineered
GEF	– Global Environment Fund
GIO	– genetically improved organisms
GM	– genetically modified
GMAC	– Genetic Modification Advisory Committee
GMO	– genetically modified organism
ha	– hectare
HRD	– human resource development
HTP	– high throughput analysis
HYV	– high-yielding variety
IAEA	– International Atomic Energy Agency
IARC	– International Agricultural Research Center
IBS	– ISNAR Biotechnology Service
ICAR	– Indian Council of Agricultural Research
ICLARM	– International Center for Living Aquatic Resources Management
ICMR	– Indian Council of Medical Research
ICRISAT	– International Crops Research Institute for the Semi-Arid Tropics
ICSRG	– International Collaboration for Sequencing the Rice Genome
IFPRI	– International Food Policy Research Institute
ILRI	– International Livestock Research Institute
IMBN	– International Molecular Biology Network
IP	– intellectual property
IPGRI	– International Plant Genetic Resource Institute
IPM	– integrated pest management
IPP	– intellectual property protection

IPR	– intellectual property right
IRPA	– Intensification of Research in Priority Areas
IRRI	– International Rice Research Institute
ISAAA	– International Service for the Acquisition of Agri-biotech Applications
ISNAR	– International Service for National Agricultural Research
LIPI	– R&D Center for Biotechnology in Bogor
LMO	– living modified organism
MAS	– marker-assisted selection
MINFAL	– Ministry of Food, Agriculture and Livestock
MIT	– Massachusetts Institute of Technology
MOF	– Ministry of Finance
MOST	– Ministry of Science and Technology
MOSTE	– Ministry of Science, Technology and the Environment (Malaysia)
MTA	– materials transfer agreement
NAP3	– Third National Agricultural Policy
NARC	– National Agricultural Research Center
NARS	– national agricultural research system
NBC	– National Biosafety Committee
NBD	– National Biotechnology Directorate (Malaysia)
NGO	– nongovernment organization
NIAB	– Nuclear Institute for Agriculture and Biology
NIBGE	– National Institute for Biotechnology and Genetic Engineering
NNSFC	– National Natural Science Foundation of China
NSF	– National Science Foundation
NPV	– nuclear polyhedrosis virus
ODA	– Overseas Development Administration
OECD	– Organisation for Economic Co-operation and Development
PAEC	– Pakistan Atomic Energy Commission
PBR	– plant breeders' right
PCR	– polymerase chain reaction
PRC	– People's Republic of China
PRSV	– papaya ringspot virus
PVP	– plant variety protection
QTL	– quantitative trait loci
RAPD	– randomly amplified polymorphic DNA
RDE	– National Research, Development and Extension

R&D	– research and development
rDNA	– recombinant DNA
RETA	– regional technical assistance
RF	– Rockefeller Foundation
RFLP	– restriction fragment length polymorphism
RM	– Malaysian ringgit
RNA	– ribonucleic acid
SNP	– single nucleotide polymorphisms
SSR	– simple sequence repeats
STS	– sequence-tagged sites
t	– ton
TTDI	– Thailand Tapioca Development Institute
TRIP	– Agreement on Trade-Related Aspects of Intellectual Property
UK	– United Kingdom
UNCED	– United Nations Conference on Environment and Development
UNDP	– United Nations Development Programme
UNEP	– United Nations Environmental Programme
UNICEF	– United Nations Children’s Fund
UNIDO	– United Nations Industrial Development Organization
UP	– University of the Philippines
UPLB	– University of the Philippines in Los Baños
UPOV	– Union pour la Protection des Obtentions Végétales (International Convention for the Protection of Plant Varieties)
US	– United States
USA	– United States of America
USAID	– United States Agency for International Development
USDA	– United States Department of Agriculture
WHO	– World Health Organization
WIPO	– World Intellectual Property Organization
wss	– white spot syndrome
wssv	– white spot syndrome virus
WTO	– World Trade Organization
YHD	– yellow head disease

NOTE

In this report, “\$” refers to US dollars.

EXECUTIVE SUMMARY

In October 1999, the Asian Development Bank (ADB) approved a strategy to reduce poverty through pro-poor, sustainable economic growth, social development, and good governance. Given the advances in biotechnology during the last decade, the importance of managing the Biotechnology Revolution in agriculture emerged as one of the principal challenges facing Asia in the future. In late 2000, ADB, in cooperation with the Australian Agency for International Development (AusAID) and the Australian Centre for International Agricultural Research (ACIAR) undertook a study on agricultural biotechnology in Asia. The objectives were to: (i) examine the risks and benefits of biotechnology in relation to human health, the environment, and agriculture; (ii) identify measures to minimize adverse impacts; (iii) explore the use of biotechnology to reduce poverty and achieve food security in Asia; and (iv) develop policies and strategies for ADB to support biotechnology in developing countries in Asia. The results of the study are reflected in this Working Paper.

A. Past Success in Reducing Poverty and Improving Food Security

About 900 million people or 75 percent of the world's poor live in Asia. They live on less than \$1 a day. About 536 million of them, including 160 million children, are undernourished. These families lack access not only to sufficient money to buy food and other essentials, but also access to adequate schooling, housing, and medical care. For those in rural areas, the environments in which they live are often short of water, fuel, and firewood. Fertile land and water for farming are increasingly scarce. For the poor people in cities, lack of money is the major constraint to obtaining nutritious food.

Although the absolute numbers of people living in poverty in Asia today are unacceptable, the situation could be much worse. In 1970, 60 percent of all Asians lived in poverty; today that figure has been cut to 30 percent. Also, countries such as Bangladesh, the People's Republic of China (PRC), and India have moved from periodic famines to virtual self-sufficiency in food production.

Science and technology underpinned the economic and social gains in Asia over the past 30 years, which in agriculture came to be known as the Green Revolution. Between 1970 and 1995, cereal production in Asia doubled, calorie availability per person increased by 24 percent, and real food prices halved. The key elements in these gains were government policies reflecting the belief that investments in increasing agricultural productivity were a prerequisite to economic development. These national policies were supported by the public and private sectors, and the international community.

This mix of supportive public policies, scientific discoveries, and public and private investments in rural Asia, particularly in irrigation, credit, and farm inputs, led to the substantial reductions in poverty and improved food security realized throughout Asia over the past 30 years. Increased agricultural productivity, rapid industrial growth, and expansion of the nonfarm rural economy have all contributed to almost a tripling of per capita gross domestic production during the period.

B. Present Problems

The intensification of agriculture and the reliance on irrigation and chemical inputs has led to environmental degradation. Much of Asia faces problems of salinity, pesticide misuse, and degradation of natural resources. The Green Revolution technologies were useful in the favorable and irrigated environments. But they had little impact on the millions of smallholders living in rainfed and marginal areas where poverty is concentrated. In addition, there have been declining public investments in the agriculture sector across the region. These factors have been responsible for the decline in annual agricultural growth rates from an average of 3.3 percent during 1977-1986 to about 1.5 percent during 1987-1996.

C. Future Challenges

During the next 25 years, the population in Asia is projected to increase from 3.0 billion to 4.5 billion. The demand for food is predicted to increase by about 40 percent from the present level of 650 million tons. This increase must come from increases in agricultural productivity in favorable areas and in rainfed and marginal areas. They will have to be

achieved with less labor, water, and arable land since there is no scope for increasing the cultivated areas. Based on current trends in population and food production in Asia, there is likely to be a large gap between food production and demand by 2025.

Strategies to meet the required increases in food supply include (i) sustainable productivity increases in food, feed, and fiber crops; (ii) reducing chemical inputs of fertilizers and pesticides and replacing them with biologically-based products; (iii) integrating soil, water, and nutrient management; (iv) improving the nutrition and productivity of livestock and controlling livestock diseases; (v) achieving sustainable increases in fisheries and aquaculture production; and (vi) increasing trade and competitiveness in global markets.

The challenge is how to use new developments in modern science (including biotechnology) in concert with information and communications technology, and new ways of managing knowledge, to make the complex agricultural systems of Asia more productive in sustainable ways.

D. Modern Scientific Developments

The pace of change in modern science has led to rapid progress in understanding the genetic basis of living organisms. That has given us the ability to develop new products and processes useful in human and animal health, food and agriculture, and the environment. In agriculture, the use of modern molecular genetics for genetic mapping and marker-assisted selection speed the development of more precise new strains of improved crops, livestock, fish, and trees. Other biotechnology applications such as tissue culture and micropropagation are used for the rapid multiplication of disease-free planting materials of horticultural crops and trees. New diagnostics and animal vaccines are being widely adopted for the diagnosis, prevention, and control of fish and livestock diseases.

The new technologies will greatly increase the efficiency of selection for valuable genes, based on knowledge of the biology of the organism, the function of specific genes, and their role in regulating particular traits. That will enable more precise selection of improved strains by crop scientists. Many of the applications of biotechnology involve the use of improved selection methods for crops and animals bred conventionally. They do not always require the development of transgenic crops and animals or other genetically modified organisms (GMOs).

The advantages of the new techniques of modern biotechnology are that they (i) speed plant and animal breeding, (ii) offer possible solutions to previously intractable problems such as drought tolerance, and (iii) enable the development of new products such as more nutritious food. However, the safety and efficacy of the new products of modern biotechnology in agriculture, particularly the development of transgenic crops and other GMOs, is the subject of often heated public debate. The challenge is how to apply the products of biotechnology safely and effectively for the benefit of small farmers in Asia.

E. Current Status of Agricultural Biotechnology in Asia

Several emerging economies in Asia, including the PRC, India, Indonesia, Malaysia, Pakistan, Philippines, Thailand, and Viet Nam, are making major investments in modern biotechnology to further the aim of improving food security and reducing poverty. In addition, several regional and international programs and a growing number of private sector companies are working on biotechnology.

The PRC is most advanced in the use of genetically modified crops. There are at least 500,000 ha of genetically modified crops grown commercially. Commercial production of transgenic cotton and soybean with resistance to insect pests is expanding. The first contribution of biotechnology toward increasing yields will be realized by decreasing losses from diseases and pests while minimizing the use of pesticides.

National biotechnology programs in Asia are being assisted through various bilateral and multilateral programs. Most support is country-specific and directed toward providing infrastructure, equipment, and postgraduate training. Multilateral assistance comes from ADB, the Food and Agriculture Organization, the United Nations Development Programme, the United Nations Industrial Development Organization, and the World Bank. World Bank projects have supported the extensive development of human resources and infrastructure for biotechnology in India and Indonesia. ADB has provided similar support to Pakistan, Philippines, Sri Lanka, and Thailand, and regional technical assistance to international agricultural research centers (IARCs).

In research and development (R&D), financial assistance also comes from the governments of Australia, Japan, and the United States through their international aid agencies, and from the Rockefeller Foundation. All

support the applications of biotechnology through specific projects. In addition, private companies and nongovernment organizations support national or regional activities. Also, several IARCs supported by the Consultative Group on International Agricultural Research, and the Asian Vegetable Research and Development Center are using new biotechnology techniques to increase the productivity of the major cereal, legume, and vegetable crops; characterize and conserve the genetic resources of crops and trees; and improve the health and increase the productivity of livestock and fish.

F. Potential Contribution of Biotechnology Toward Poverty Reduction and Food Security

Agricultural biotechnology is expected to contribute significantly toward poverty reduction and food security in Asia through increased productivity, lower production costs and food prices, and improved nutrition. That is because much of public sector R&D has emphasized simple, low cost technology appropriate for poor farmers in the rainfed and marginal areas, despite human resource and financial constraints that hinder progress. The focus has been on the so-called orphan crops (rice, tropical maize, wheat, sorghum, millet, banana, cassava, groundnut, oilseed, potato, sweetpotato, and soybean) that the private sector has largely ignored because of their low return on investment. Enhancing cooperation between the public and private sectors would speed development.

Modern plant breeding may help to achieve productivity gains, introduce resistance to pests and diseases, reduce pesticide use, improve crop tolerance for abiotic stress, improve the nutritional value of some foods, and enhance the durability of products during harvesting and shipping. Biotechnology may offer cost-effective solutions to vitamin and mineral deficiencies by developing rice varieties that contain vitamin A and minerals. Raising productivity could increase smallholders' incomes, reduce poverty, increase food access, reduce malnutrition, and improve the livelihoods of the poor. In the PRC, cotton farmers that have adopted insect-resistant, transgenic Bt cotton have reduced their use of highly toxic insecticides. That in turn has reduced farmers' crop protection costs and benefited both the environment and public health. A real problem is how to provide adequate incentives for crop breeders to focus on orphan

crops and adaptations to difficult environments, which are of greater interest to poor farmers. Public funding and the involvement of international organizations will be crucial to such research.

G. Key Issues

1. Potential Risks of Biotechnology

The public debate on biotechnology has been focused on GMOs, one of the many products of biotechnology. The public perception is that genetically engineered foods and crops may have food biosafety, environmental, socioeconomic, and ethical risks. Some of these risks are genuine and need to be addressed by the public and private sectors to ensure that GMOs are widely accepted. An open, transparent, and inclusive food safety policy and regulatory process is required.

The potential long-term impact of genetically improved foods on human health and the environment is unknown, and requires monitoring and further research. Methods are available to test allergenicity and toxicity of genetically modified foods in humans before approving them for human consumption.

Six environmental safety issues need to be considered when addressing risks posed by the cultivation of genetically modified plants: gene transfer, weediness, trait effects, genetic and phenotypic variability, expression of genetic material from pathogens, and worker safety. The Cartagena Protocol on Biosafety, agreed to by 130 governments in January 2000, specifies obligations for international transfer of living modified organisms. It also sets out means of risk assessment and management, advance informed agreement, technology transfer, and capacity building. The Protocol establishes a Biosafety Clearing-House through which governments signal whether or not they will accept imports of agricultural commodities that include GMOs. Further, it establishes labeling requirements for shipments of commodities that may contain GMOs. Developing countries in Asia will need to strengthen their biosafety regulations and enforcement to ensure that the risks of biotechnology can be minimized. Public awareness activities from the onset of a biotechnology work program can greatly assist in gaining consumer acceptance of biotechnology products.

2. Intellectual Property Management

A set of intellectual property right (IPR) issues is associated with biotechnology. They include (i) lack of access of poor farmers to the new technologies and products, (ii) losses of ownership rights of some developing countries over their own indigenous genetic resources, (iii) lack of incentives for the free flow of technologies and products from developed to developing countries, and (iv) a growing danger that the free flow of agricultural materials between countries will be impeded. The public and private sectors need to manage intellectual property to ensure that IPRs do not exclude developing countries from access to the benefits of new technology.

3. Economic Concentration in Agricultural Biotechnology

Multinational companies in the seeds, agricultural chemicals, pharmaceuticals, and food processing industries in developed countries play a major role in biotechnology research. They have invested heavily in in-house research facilities, commissioned research, taken equity positions in new biotechnology firms, or entered into contractual arrangements with public research institutions or universities. The development of new biotechnology applications in agriculture has become increasingly concentrated in the hands of a decreasing number of companies as a result of mergers and acquisitions. In the short term, most genetically engineered crops will be developed and grown in developed countries by large-scale farmers. Changing patterns of international trade in foods that result from genetic engineering in developed countries could have serious consequences for some developing countries in Asia.

4. Need for Increased Public-Private Sector Collaboration

Public investment in agricultural biotechnology is crucial for achieving future food security and reducing poverty. The private sector is unlikely to undertake much of the R&D needed by small farmers because it sees little potential for return on investment. Accelerated public investments are needed to develop biotechnology applications that address difficult problems in rainfed and marginal areas. And additional private and philanthropic resources are required because most governments in Asia have limited resources to finance biotechnology research. Currently, it is the

private sector that has the knowledge, skills, and capital to solve the problems of small farmers. Financial incentives or policy initiatives are essential for increased collaboration in biotechnology R&D between the public and private sectors.

5. Policy and Priority Setting

Considerable biotechnology R&D is already being carried out in Asian countries, particularly in the more developed countries such as PRC, India, Indonesia, Philippines, and Thailand. They and other Asian countries should establish clear policies and priorities in agricultural biotechnology R&D to ensure that the output will contribute significantly toward poverty reduction and food security. Policies will need to take into account (i) the high level of capital and technical skills biotechnology requires, (ii) the often inadequate capacity that constrains public and private biotechnology R&D in developing countries, (iii) the reluctance of the private sector to invest in technology for Asia's poor farmers, (iv) the inherent risks in some uses of biotechnology, and (v) the difficulty of establishing and implementing effective biosafety regimes.

H. Conclusions and Recommendations

The major conclusion of this study is that the governments and funding agencies should continue and increase their investments in biotechnology as a means of achieving their goals of poverty reduction and food security in Asia over the next 25 years. Achieving these goals with presently available technologies will be difficult, given the present trends and challenges facing the rural sector in Asian environments. Accordingly, it is recommended that the following measures be considered by ADB and the governments in the region.

1. General Strategy

To ensure that agricultural biotechnology will contribute to reducing poverty and improving food security in Asia, biotechnology R&D should do the following:

- (i) Address the problems of small farmers in the rainfed and marginal areas where most of the poor live, yet not neglect the problems of small farmers in the irrigated areas.
- (ii) Focus on economically important orphan crops, high value crops, and livestock to increase their productivity.
- (iii) Develop low cost, appropriate technologies for small farmers, particularly the development of HYVs adapted to the rainfed and marginal areas.
- (iv) Develop, test, and release technologies that will pose minimal or no risks to human health and the environment.
- (v) Strengthen the extension, delivery, and regulatory systems to ensure that improved varieties and technologies will be disseminated widely to small farmers with little or no risk to consumers or the farmers themselves.

2. Role of Government

To use agricultural biotechnology safely and effectively for the benefit of small farmers in Asia, governments in the region should:

- (i) Demonstrate a strong commitment to agriculture and rural development by providing adequate budget and staffing to the sector in general and agricultural biotechnology in particular.
- (ii) Establish clear policies and priorities in biotechnology R&D to ensure that it can contribute effectively and safely toward poverty reduction and food security.
- (iii) Enhance cooperation with the private sector in the development of biotechnology that will benefit small farmers.
- (iv) Set up effective biosafety regulatory and enforcement systems to ensure that the risks of biotechnology (particularly those of genetically modified crops and livestock) will be minimized.
- (v) Enact IPR laws that will protect and stimulate private sector investments in biotechnology in the region.
- (vi) Organize dialogue with nongovernmental organizations, consumers, and farmers on the benefits, risks, and opportunities in the use of new biotechnology.
- (vii) Seek assistance from international organizations and funding agencies on specific problems in biotechnology that cannot be addressed using their own resources.

3. Suggested Policy for ADB on Agricultural Biotechnology

- (i) Assist DMCs in policy and priority setting to enhance investments in the safe applications of biotechnology.
- (ii) Increase dialogue with its DMCs in identifying potential benefits and opportunities in the use of different biotechnologies to address specific targets.
- (iii) Strengthen risk assessment and management capabilities in its DMCs through systematic capacity building.
- (iv) Facilitate access to proprietary technologies and encourage greater private and public sector cooperation in the development and delivery of new products at affordable prices for the poor.
- (v) Support a strategic R&D agenda and associated human resources development in Asia to generate new knowledge and disseminate the results for the public good. It should support and fund national governments and IARCs to undertake important initiatives that will have significant impact on poverty reduction and food security in the long term in areas of market failure where the private sector is unlikely to invest.

I INTRODUCTION

At the dawn of the twenty-first century, about 900 million or 68 percent of the world's poor people¹ live in Asia; about 500 million in South Asia, 300 million in East Asia, and 100 million in Southeast Asia and the Pacific (World Bank 1999). In addition, about 526 million people, including 160 million children, are undernourished² (FAO 1999c). Not only do they lack access to sufficient money to buy food and other essentials, but neither do they have access to sufficient schooling, adequate housing, nor medical care. Those in rural areas are often short of water and fuel. Fertile land and water for farming are increasingly scarce. Urban poor lack money to buy enough food. That which they can afford may be deficient in protein and essential vitamins and minerals.

Although the absolute numbers of people living in poverty in Asia today are unacceptable, the situation could be much worse. In 1970, 60 percent of all Asians lived in poverty. That figure has been cut by almost half, with about one third of all Asians living in poverty in 2000. Also, countries such as Bangladesh, the People's Republic of China (PRC), and India have moved from periodic famines to almost self-sufficiency in food production. However, further efforts are needed to reduce poverty by another 50 percent by 2015, as targeted by world leaders during the World Food Summit in 1997. The latter half of the twentieth century saw impressive advances in science and technology. We now have the capacity to apply this knowledge to reduce poverty and improve food security. This Working Paper discusses how biotechnology can be used to safely and effectively reduce poverty and improve food security in Asia.

A. Past Successes in Reducing Poverty Through Agricultural Science

Science and technology underpinned the economic and social gains in Asia over the past 30 years. In agriculture, these gains came to be known as the Green Revolution. Between 1970 and 1995, cereal produc-

¹ The poor is defined as those people who survive on less than \$1.00 day.

² Undernutrition is determined from data about people's weight, height, and age.

tion in Asia doubled, calorie availability per person increased by 24 percent, and real food prices halved (IFPRI 1997). Although the region's population grew by 1 billion people, overall food production more than kept pace with population growth (McCalla 1998). These food production increases were achieved largely by the cultivation of high-yielding varieties (HYVs) of rice and wheat, accompanied by expansion of irrigated areas, increases in fertilizer and pesticide use, and greater availability of credit.

The scientific basis for the Green Revolution stemmed from national and international research programs that led to the development and distribution of new HYVs, particularly of rice and wheat. The first generation of these new varieties were based on the introduction of new genes for dwarfing that made the HYVs shorter, more responsive to fertilizers, and less prone to falling over or lodging when fertilized and irrigated. Subsequent varieties also carried genes that gave increased pest and disease resistance and improved taste and grain quality.

The key elements in improving food security in Asia from 1970-95 were government policies reflecting a belief that investments in increasing agricultural productivity were a prerequisite to economic development. These national policies were supported by political leaders in Asia and by both the public and private sectors of the international community. This mix of supportive public policies, scientific discoveries, and public and private investments in rural Asia, particularly in irrigation, credit, and inputs, led to substantial reductions in poverty and improved food security throughout Asia over the past 30 years. Increased agricultural productivity, rapid industrial growth, and expansion of the nonfarm rural economy have all contributed to almost a tripling of per capita gross domestic product across Asia since 1970 (ADB 2000b, Pinstrup-Andersen and Cohen 2000).

B. Present Problems

Despite these successes, problems remain. The intensification of agriculture and the reliance on irrigation and chemical inputs has led to environmental degradation, increased salinity, and pesticide misuse. Deforestation, overgrazing, and overfishing also threaten the sustainable use of natural resources.

Green Revolution technologies had little impact on the millions of smallholders living in rainfed and marginal areas, where poverty is concentrated. Furthermore, the Green Revolution has already run its course

in much of Asia. Wheat and rice yields in the major growing areas of Asia have been stagnant or declining for the past decade, while population continues to increase (Pingali et al. 1997). The key lessons learned from the Green Revolution are: (i) it has benefited farmers in irrigated areas much more than farmers in rainfed areas thus worsening the income disparity between the two groups, (ii) it overlooked the rights of women to also benefit from the technological advances, and (iii) it promoted an excessive use of pesticides that are harmful to the environment.

As countries became self sufficient in food, government investments declined in the agricultural sector and in science and technology across the region. This reflects a worldwide trend toward declining public investments in the rural sector and in agricultural research and development (R&D), nationally and internationally.

In Asia, private sector investments in the rural sector and related R&D have concentrated on export commodities. The downward trends in public investments by governments and development agencies in smallholder agriculture over the past decade have not been matched by a concomitant rise in private investments. Similarly, there is little (and few incentives for) private R&D on the food crops, livestock, fisheries, and aquaculture systems important for food security and poverty reduction in rural Asia.

C. Future Challenges

The population of Asia is projected to increase from 3.0 billion to 4.5 billion in the next 25 years. During the same period, the urban population will nearly double from 1.2 billion to 2.0 billion, as rural people move to the cities in search of employment. These increases will place massive pressure on developing member countries (DMCs) of ADB to increase food production. Food demand is influenced by population growth, urbanization, income, and associated changes in dietary preferences. Urbanization and income growth frequently lead to shifts from a diet based on root crops (cassava, yam, and sweetpotato), sorghum, millets, and maize to rice and wheat, which require less preparation time, and to more meat, milk, fruits, vegetables, and processed foods. This dietary transition has already happened in much of the region (ADB 2000b). Meeting the food needs of Asia's growing and increasingly urbanized population requires increases in agricultural

productivity and matching these increases to dietary changes and rising incomes.

To meet this demand, cereal production will need to be increased by at least 40 percent from the present level of about 650 million tons annually, most of which will have to come from yield increases. In addition, meat demand will double during the period (Pinstrup-Andersen et al. 1999). Production increases will have to be achieved by increasing yields in a sustainable way to conserve diminishing and degraded natural resources. Nearly all of these production increases will need to take place in DMCs themselves because on average 90 percent of the world's food is consumed in the country where it is produced. Food imports are not only expensive but discourage the creation of employment, which is badly needed in the rural areas.

In this millennium, we face a food, feed, and fiber production challenge in highly complex farming systems for several reasons:

- (i) Water will become the most important limiting factor in agricultural production because the quality and quantity of water will decline as a result of pollution, forest degradation, and increased agricultural, domestic, and industrial use (ADB 2001).
- (ii) Urbanization will mean the loss of agricultural land to residential and industrial development, and a decline in the number of farm workers.
- (iii) Most farmers are poor with small landholdings.
- (iv) Farming systems are commonly heterogeneous with mixes of food crops, livestock, and trees.
- (v) About 70 percent of the cultivated land is rainfed with unreliable distribution and intensity of rainfall.

Thus, the increase in food production during the next 25 years will have to be achieved using less labor, water, and cultivated land. This can be done only if scientists can develop new crop varieties with high yield potential and high water use efficiency. New understanding of plant and animal genes may offer ways to increase crop yields to the levels required to adequately and sustainably feed the growing population in Asia. Thus, developments in modern biotechnology could make extremely important contributions to future agricultural growth, food security, and poverty reduction. Increasing smallholder agriculture productivity will not only

increase food supplies, but will reduce poverty and malnutrition, increase food access, and, improve living standards of the poor (McCalla and Brown 2000).

D. Rationale for ADB's Involvement in Biotechnology

Biotechnology has the potential to (i) increase crop and animal productivity; (ii) improve nutritional quality; (iii) broaden tolerance of crops for drought, salinity, and other abiotic stresses; and (iv) increase resistance of crops to pests and diseases. These potential benefits will have significant impact in increasing food production and reducing poverty in DMCs if they can be applied to problems of the poor farmers in the tropics. As with any technology, biotechnology brings with it potential risks. To maximize the benefits and minimize the risks, the introduction and use of biotechnology in DMCs or elsewhere must be thoughtfully managed by the public and private sectors. The key risks that relate to the application of new developments in biotechnology for the public good are food and environmental safety, economic concentration, and intellectual property (IP) management.

To explore the opportunities and risks of biotechnology, ADB has decided to undertake a comprehensive study on the use of biotechnology to reduce poverty and achieve food security in cooperation with the Australian Centre for International Agricultural Research (ACIAR)/ Australian Agency for Agricultural Development (AusAID). There are many reasons to support this initiative:

- (i) As a premiere development institution, ADB should be well informed on the development of biotechnology and the issues surrounding modern biotechnology.
- (ii) Biotechnology has been identified by the Rural Asia Study as one of the emerging challenges in Asia (ADB 2000b).
- (iii) Biotechnology has been identified by the Consultative Group on International Agricultural Research (CGIAR) as a powerful tool to fight poverty when used in conjunction with other agricultural research (Persley and Lantin 2000).
- (iv) ADB is responsible for assisting the DMCs in dealing with potential risks of biotechnology and providing information on various biotechnology issues.

- (v) ADB's Policy on Agriculture and Natural Resources Research recommends that ADB support research to increase farm productivity through modern biotechnology approaches, while giving appropriate consideration to indigenous and traditional knowledge (ADB 1995).

E. ADB's Poverty Reduction Strategy

While the need for further intensification of agricultural production in Asia is clear, intensification strategies must change to avoid adverse environmental impact and to reverse the effects of earlier practices. Enhanced, but inefficient use of irrigation and mineral fertilizers over the past three decades has had negative side effects such as soil salinity and nutrient leaching. With crop intensification, incidences of pests and diseases also increased (Pinstrup-Andersen and Cohen 2000).

The following strategies are needed to meet the food demand in Asia over the next 25 years.

- (i) Sustainable productivity increases in food, feed, and fiber crops.
- (ii) Reducing chemical inputs of fertilizers and pesticides and replacing these with biologically based products.
- (iii) Integrating soil, water, and nutrient management.
- (iv) Improving the nutrition and productivity of livestock and controlling livestock diseases.
- (v) Sustainable increases in livestock, fisheries, and aquaculture production.
- (vi) Increasing trade and competitiveness in global markets.

As rural poverty persists in Asia, agriculture will play a prominent role in achieving equitable and sustainable rural growth in the twenty-first century. Even when rural people do not work directly in agriculture, they rely on nonfarm employment and income closely related to agriculture. Where there are large numbers of rural poor, agricultural growth is a catalyst for broad-based economic growth and development. Agriculture's linkages to the nonfarm economy generate employment, income, and growth in the rest of the economy. A healthy agricultural economy also offers incentives for natural resource conservation (Pinstrup-Andersen and Cohen 2000).

The ADB Poverty Reduction Strategy (ADB 1999) sees three factors, pro-poor, sustainable economic growth; good governance; and social development as key elements for reducing poverty. Biotechnology may contribute toward achieving the poverty reduction goals in several components of the strategy:

- (i) Increasing priority for agriculture and rural development.
- (ii) Addressing environmental considerations.
- (iii) Increasing the public and private sector roles in poverty reduction.
- (iv) Encouraging regional and subregional cooperation.
- (v) Coordinating efforts of funding agencies.

The challenge is how to use new scientific developments such as biotechnology, together with information and communications technology, to make the complex agricultural systems of Asia more productive and sustainable. Good governance is also crucial to ensure that new agricultural biotechnology reaches the poor.

F. Key Questions

It is in the context of this complex and evolving situation, that this report will address three key issues:

- (i) What are the potential benefits and risks of agricultural biotechnology on human health, the environment, and agriculture; how can we minimize the risks and enhance the benefits?
- (ii) How can we use biotechnology to reduce poverty and achieve food security in Asia?
- (iii) What policies and strategies should be considered by funding agencies, including ADB, to support biotechnology for the benefits of small farmers in Asia?

II SCIENTIFIC CONTEXT

A. Promethean Science

The pace of change in modern science has led some to term it Promethean science, acknowledging both its risks and benefits (Serageldin and Persley 2000). Modern science encompasses new developments in the biological, physical, and social sciences. In biology, discoveries over the past 20 years allow the better understanding of the structure and function of human, animal, and plant genes.

At the same time, new discoveries in the physical sciences underpin the revolution in information and communications technologies. Geographic information systems enable characterization of agro-ecosystems and offer means by which new technologies can be customized to the needs of particular agro-ecosystems. The biological and physical sciences also interact in new ways. For example, the ability to analyze large volumes of data is a critical component of various genome projects that are mapping all the genes in an organism, as in the Human Genome Project.

New developments in the social sciences underpin community participation in technology development and evaluation (sometimes termed agro-ecological methods). Participatory methods developed in the social sciences can help in understanding problems and the researchable issues, particularly those of small farmers operating in marginal environments. They may also be used to clarify the concerns of rural and urban dwellers in regard to the deployment of new technologies, including the products of biotechnology.

Integration of all branches of modern science and traditional knowledge is required to develop knowledge-intensive solutions to the problems of rural Asia. These solutions need not be only technically feasible but also socially acceptable. Indeed, the potential value of modern science to agriculture and the environment in Asia will require the efforts of all stakeholders, including civil society, farmer cooperatives, producers, consumers, governments, and development agencies.

B. Definition, History, and Scope of Biotechnology

Biotechnology, broadly defined, includes any technique that uses living organisms, or parts of such organisms, to make or modify products, to improve plants or animals, or to develop microorganisms for specific use. It ranges from traditional biotechnology to the most advanced modern biotechnology. Biotechnology is not a separate science but rather a mix of disciplines (genetics, molecular biology, biochemistry, embryology, and cell biology) converted into productive processes by linking them with such practical disciplines as chemical engineering, information technology, and robotics. Modern biotechnology should be seen as an integration of new techniques with the well-established approaches of traditional biotechnology such as plant and animal breeding, food production, fermentation products and processes, and production of pharmaceuticals and fertilizers (Doyle and Persley 1996).

The key components of modern biotechnology are listed below.

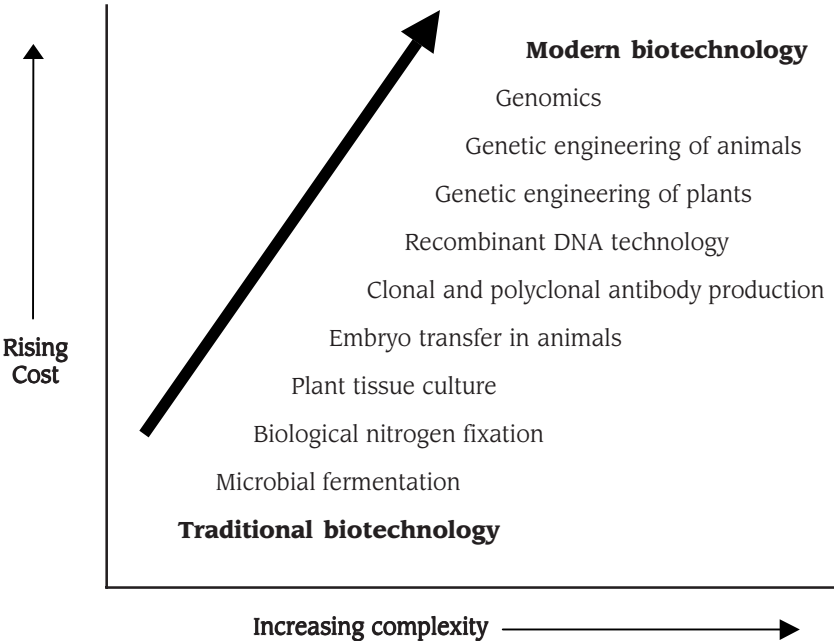
- (i) Genomics: The molecular characterization of all genes in a species.
- (ii) Bioinformatics: The assembly of data from genomic analysis into accessible forms, involving the application of information technology to analyze and manage large data sets resulting from gene sequencing or related techniques.
- (iii) Transformation: The introduction of one or more genes conferring potentially useful traits into plants, livestock, fish and tree species.
- (iv) Genetically improved organism.
- (v) Genetically modified organism (GMO).
- (vi) Living modified organism (LMO).
- (vii) Molecular breeding: Identification and evaluation of useful traits in breeding programs by the use of marker-assisted selection (MAS);
- (viii) Diagnostics: The use of molecular characterization to provide more accurate and quicker identification of pathogens; and
- (ix) Vaccine technology: The use of modern immunology to develop recombinant deoxyribonucleic acid (rDNA) vaccines for improved control of livestock and fish diseases (Doyle and Persley 1999).

Biotechnology consists of a gradient of technologies, ranging from the long-established and widely used techniques of traditional biotechnology to novel and continuously evolving modern biotechnology techniques (Figure 2.1).

During the 1970s scientists developed new methods for precise recombination of portions of deoxyribonucleic acid (DNA), the biochemical material in all living cells that governs inherited characteristics, and for transferring portions of DNA from one organism to another. This set of enabling techniques is referred to as rDNA technology or genetic engineering.

Modern biotechnology presently includes the various uses of new techniques of rDNA technology, monoclonal and polyclonal antibodies, and new cell and tissue culture methods. A chronology of the development of modern biotechnology is given in Table 2.1. Over the past two decades the number of significant advances in modern biotechnology for

Figure 2.1 Gradient of Biotechnologies



Source: Persley (1990) and Doyle and Persley (1996).

understanding and modifying the genetics of living organisms has increased dramatically. That has led to greatly increased interest and investment in biotechnology, and increasing concerns as to the power of the new technologies and their safety (see Appendix 1 for details).

C. Economic Concentration in Agricultural Biotechnology

Modern biotechnology R&D has been conducted in an institutional and economic environment that differs significantly from the development of the earlier Green Revolution technologies. While the latter were essentially the prerogative of public research institutions and philanthropic foundations, the application of modern biotechnology to agriculture is essentially a competitive, commercial endeavor in which powerful private sector interests compete. Similarly, while the Green Revolution technologies were essentially dedicated to the public, the strengthening and extension of IP protection, particularly since the conclusion of the Uruguay Round of trade negotiations has increased the private character of biotechnologies.

Multinational companies in the seed, agricultural chemical, pharmaceutical, and food-processing industries play a major role in biotechnology research. They have invested heavily in in-house research facilities, commissioned research, taken equity positions in new biotechnology firms, and entered into contractual arrangements with public research institutions or universities. As a result of mergers and acquisitions in the past few years, the development of new biotechnology applications in agriculture has become increasingly concentrated in the hands of a decreasing number of companies. The dominant companies that operate within global markets are Aventis, AgrEvo, Dow, DuPont, Monsanto, and Syngenta.

**Table 2.1: The Evolution of the Science of Genetics,
Leading to Modern Biotechnology**

1866	Mendel postulates a set of rules to explain the inheritance of biological characteristics in living organisms.
1900	Mendelian law rediscovered after independent experimental evidence confirms Mendel's basic principles.
1903	Sutton postulates that genes are located on chromosomes.
1910	Morgan's experiments prove genes are located on chromosomes.
1911	Johannsen devises the term "gene", and distinguishes genotypes (determined by genetic composition) and phenotypes (influenced by environment).
1922	Morgan and colleagues develop gene mapping techniques and prepare gene map of fruit fly chromosomes, ultimately containing over 2000 genes.
1944	Avery, MacLeod and McCarty demonstrated that genes are composed of DNA rather than protein.
1952	Hershey and Chase confirm role of DNA as the basic genetic material.
1953	Watson and Crick discover the double-helix structure of DNA.
1960	Genetic code deciphered.
1971	Cohen and Boyer develop initial techniques for rDNA technology, to allow transfer of genetic material from one organism to another.
1973	First gene (for insulin production) cloned, using rDNA technology.
1974	First expression in bacteria of a gene cloned from a different species.
1976	First new biotechnology firm established to exploit rDNA technology (Genentech in USA).
1980	USA Supreme Court rules that microorganisms can be patented under existing law (Diamond v. Chakrabarty).
1982	First rDNA animal vaccine approved for sale in Europe (colibacillosis). First rDNA pharmaceutical (insulin) approved for sale in USA and UK. First successful transfer of a gene from one animal species to another (a transgenic mouse carrying the gene for rat growth hormone). First transgenic plant produced, using an agrobacterium transformation system.
1983	First successful transfer of a plant gene from one species to another.
1985	US Patent Office extends patent protection to genetically engineered plants.
1986	Transgenic pigs produced carrying the gene for human growth hormone.
1987	First field trials in USA of transgenic plants (tomatoes with a gene for insect resistance). First field trials in USA of genetically engineered microorganism.
1988	US Patent Office extends patent protection to genetically engineered animals. First GMO approved. Human genome mapping project initiated.
1989	Plant genome mapping projects (for cereals and <i>Arabidopsis</i>) initiated.
2000	Plant genome mapping projects for rice and <i>Arabidopsis</i> completed, and about 44 million hectares of land planted to GMO crops.

DNA = deoxyribonucleic acid, GMO = genetically modified organism, rDNA = recombinant DNA, UK = United Kingdom, USA = United States of America.

Source: Adapted from Persley (1990).

Biotechnology R&D has been concentrated in a limited number of industrialized countries, with the United States (US) in the lead in financial and human resources. A growing number of developing countries have invested in biotechnology R&D, but the amounts are small compared to the sums invested by private companies in the industrial world. While private sector investment in agricultural research in general is increasing in developed countries, there is still little private sector biotechnology research effort in developing countries, particularly in Asia (Pinstrup-Andersen and Cohen 2000).

The commercialization and distribution of new agricultural biotechnology products, particularly transgenic crops, is also concentrated in Organisation for Economic Co-operation and Development (OECD) member countries, with a few exceptions (James 2000). These products are for the most part crops of economic importance in industrial country agricultural production and in world trade in agricultural commodities, mainly soybean, maize, cotton, and canola. During the past five years, the area under GMOs³ has increased rapidly from 1.7 million ha to 44.4 million ha, 75 percent of which are in the US. The remaining 25 percent are distributed in both developed and developing countries, including Argentina, Australia, Bulgaria, Canada, PRC, France, Germany, Mexico, Portugal, Romania, South Africa, Spain, Ukraine, and Uruguay (Appendix 2).

Relatively little biotechnology research is being undertaken on the problems of small farmers in rainfed and marginal lands. Neither is there much interest in Asia's basic food crops: rice, tropical maize, wheat, sorghum, millet, banana, cassava, groundnut, oilseed, potato, sweetpotato, and soybean. These are considered *orphan crops* because of the private sector's reluctance to work on them. That focus is unlikely to change because of the perception that investments in such orphan crops and from working on problems of small farmers yield limited returns. To participate more fully in the biotechnology revolution, Asian governments will need to expand their capacities to undertake biotechnology research linked to the problems of small farmers and orphan crops. In certain situations, however, there may be opportunities to purchase, license, or import technology applicable in Asia.

³ The term genetically modified organism (GMO) is synonymous with living modified organism (LMO), genetically engineered organism, genetically improved organism, and transgenic material.

D. Applications of Biotechnology

The applications developed from the new methods in biotechnology place them within the continuum of techniques used throughout human history in industry, agriculture, and food processing. Thus, while modern biotechnology provides powerful new tools, they are used to generate products that fill similar roles to those produced with more traditional methods.

There is now increasing use of modern molecular genetics for genetic mapping and MAS as aids to more precise and rapid development of new strains of improved crops, livestock, fish, and trees. Other biotechnology applications such as tissue culture and micropropagation are being used for the rapid multiplication of horticultural crops and trees. New diagnostics and vaccines are being widely adopted for the diagnosis, prevention, and control of fish and livestock diseases (see the summary in Table 2.2 and details in Appendix 2).

The science of genomics (the molecular characterization of all the genes in a species) has dramatically increased knowledge of plant genes and their functions. The new technologies enable greatly increased efficiency of selection for useful genes, based on knowledge of the biology of the organism and the role of specific genes in regulating particular traits. This will enable more precise selection of improved strains. These techniques may be used for more efficient selection in conventional breeding programs. They may also be used for the identification of genes suitable for use in the development of transgenic crops. Thus far, scientists have completed genomic study on rice through the cooperative efforts of several international and private sector institutions led by Japan.

Modern biotechnology permits increased precision in the use of new techniques and a shorter time to produce results. For example, plant breeders and molecular biologists can collaborate to transfer to a highly developed crop variety one or two specific genes to impart a new character such as a specific kind of pest resistance.

Table 2.2: Summary of Applications of Modern Biotechnology to Agriculture

Subsector	Applications
Crop Production	<p>Diagnostics. To diagnose plant pests and pathogens, contaminants, and quality traits.</p> <p>Micropropagation techniques or tissue culture. To multiply disease-free planting materials on a large-scale.</p> <p>Development of transgenic crops. To develop commercially new genetically modified crop varieties.</p> <p>Modern plant breeding. To develop superior plant varieties rapidly and more precisely.</p> <p>Marker-assisted selection. To use genetic markers, maps, and genomic information in breeding for high yielding, disease- and pest-resistant varieties.</p>
Biodiversity Forestry	<p>Characterizing, conserving, and using biodiversity.</p> <p>Gene-mapping. To accelerate tree breeding.</p> <p>Macropropagation. Rapid vegetative propagation by means of cuttings from large plantation of pines and other trees.</p> <p>Micropropagation by tissue culture. Large-scale multiplication of genetically superior plantlets.</p> <p>DNA finger printing. To differentiate species, strains, and cultivars accurately.</p> <p>Wood security. The selection of genetically superior trees for breeding purpose.</p>
Livestock Production	<p>Livestock improvement. To speed up the reproduction process in animals, allowing more generations to be produced.</p> <p>Transgenic livestock. Development of transgenic lines of virus-resistant poultry and other animals.</p> <p>Livestock health. Application of diagnostics for the control of major diseases of livestock.</p> <p>Vaccine development. Development of vaccines for the control of epidemic viral diseases of livestock.</p>
Fisheries	<p>Transgenic fish. Still being explored.</p> <p>Use of molecular markers in biodiversity. Research, genomic mapping, and trait selection in fish and other aquatic organisms.</p>

Source: Consultants' assessment.

New techniques of modern biotechnology accelerate plant and animal breeding. They offer possible solutions to previously intractable problems and difficult targets such as drought tolerance, and enable the development of new products (Table 2.2). These products may include more nutritious food, crop varieties with improved tolerance for pests and diseases, and animal vaccines.

It is important to provide appropriate regulatory mechanisms to ensure that products produced by modern biotechnology are as safe as the products of traditional biotechnology. That is especially so when the products are GMOs that might interact with the environment. Our knowledge of genes is not matched by our knowledge of the gene-environment interaction or potential impacts of biotechnology on the environment. However, many of the Green Revolution technologies were also introduced without such understanding. At present, there is widespread distrust of biotechnology and the public needs to be engaged in dialogue before the technology is disseminated widely.

III PRESENT STATUS OF AGRICULTURAL BIOTECHNOLOGY IN ASIA

A. Selected Country Experiences

Several governments in Asia are committed to the use of modern biotechnology in agriculture. They have devoted significant human and financial resources to this policy over the past two decades. Some illustrations of current activities in selected countries are given below. Further details on individual countries are contained in Appendixes 3 to 10 and summarized in Table 3.1.

The PRC accords high priority to biotechnology to increase food production and improve product quality in an environmentally sustainable manner. The PRC has moved quickly to adopt new biotechnologies, particularly genetically modified crops. The country is rapidly increasing its expenditure on biotechnology R&D. Over 103 genes have been evaluated for improving traits in 47 plant species. New traits have been introduced and evaluated in field tests on rice, wheat, maize, cotton, tomato, pepper, potato, cucumber, papaya, and tobacco. A variety of traits have been targeted. They include resistance to diseases, pests, and herbicides, and quality improvement.

Approximately 50 genetically modified varieties have been approved for environmental release, or small-scale field testing in the PRC. A few new genetically improved varieties have been approved for large-scale commercial production. The most widespread are new pest-resistant varieties of cotton that are being widely cultivated by farmers. These were grown commercially by approximately 3 million farmers on approximately 500,000 ha in 2000. Several new products are in the pipeline for potential commercialization (Zhang 2000).

India has allocated large public resources toward human resources development and infrastructure in biotechnology. In the early 1980s, the Government of India created a Department of Biotechnology to promote the use of new biotechnologies in industry, medicine, and agriculture. Current R&D efforts in India are directed toward increasing agricultural productivity, bioremediation in the environment, medical and industrial biotechnology, and bioinformatics (Sharma 2000). R&D priorities in agriculture include new regeneration techniques for the rapid multiplication

of citrus, coffee, mangrove, vanilla, and cardamom. Cardamom yield has increased 40 percent through the use of tissue culture.

There is substantial private sector participation in biotechnology in India, for example, in the seed sector, the veterinary products sector, and bioinformatics linked with the booming information technology sector (Dhawan 2001). Further, organizations like the M.S. Swaminathan Research Foundation have developed innovative approaches such as the ADB-supported BioVillages program that is fostering the growth of new income-raising technologies. Emphasis is on developing small-scale bioindustries for women (Lakshmi 2001).

Indonesia has placed a high priority on biotechnology over the past 15 years. The Government has designated three National Biotechnology Centers to coordinate R&D in agriculture, medicine, and industrial microbiology. Applications of biotechnology to agriculture are primarily the responsibility of the Agency for Agricultural Research and Development (AARD). A National Committee on Biotechnology advises the minister in developing guidelines for government policy in the promotion of biotechnology. In recent years there has been an extensive training program within Indonesia and abroad to upgrade skills of scientists involved in biotechnological research. In the 1980s, a major World Bank loan of over \$100 million financed the creation of three inter-university centers for agricultural, medical, and industrial biotechnology. More recently, a current World Bank loan is financing facilities for agricultural biotechnology within AARD.

Crop improvement efforts using modern biotechnology started in Pakistan in 1985, when a training course was held on recombinant DNA. Work is now concentrated on chickpea, rice, and cotton. Field evaluation is hampered by lack of biosafety regulations. There is some private investment in R&D of agricultural biotechnology. The government controls testing, multiplication, distribution, and biosafety issues for genetically modified crops. Pakistan lacks firm policy and regulations regarding intellectual property rights (IPR) and patents involving biotechnology, and biosafety regulations for GMOs (Zafar 2001).

The Philippines began its modern biotechnology programs in 1980 with the creation of the National Institutes of Molecular Biology and Biotechnology in Los Baños, with a focus on agricultural biotechnology. In 1997, the Agriculture Fisheries Modernization Act recognized biotechnology as a major strategy to increase agricultural productivity. The Act provided a budget for agricultural biotechnology of almost \$20 million

annually for the next 7 years (4 percent of the total R&D budget). In 1998, the government funded these five high-level biotechnology research projects to develop

- (i) new varieties of banana resistant to banana bunchy top virus and papaya resistant to ringspot virus,
- (ii) delayed ripening papaya and mango,
- (iii) insect-resistant maize,
- (iv) marker-assisted breeding in coconut, and
- (v) coconut oil with high lauric acid content.

Nongovernment organizations (NGOs) and other groups concerned about the safety of GMOs have been vocal in the Philippines. This is affecting field-testing and commercialization of transgenic crops. Products in the regulatory pipeline include new varieties of insect-resistant maize and insect- and disease-resistant rice.

Thailand is focusing on the applications of biotechnology to traditional foods, fruits, and export commodities such as shrimp. R&D priorities are to increase production and reduce production cost on crops such as rice, cassava, sugarcane, rubber, durian, and orchids. An early success in Thailand has been the development of new molecular diagnostics for the diagnosis and control of virus diseases in shrimp. These diseases cost the shrimp export industry over \$500 million in lost production in 1996. The development and commercial use of the new diagnostics prevents the loss of an estimated 20–50 percent of annual production, a saving of at least \$100 million per year.

There are also active agricultural biotechnology programs in Bangladesh, Malaysia, Nepal, Sri Lanka, Singapore, and Viet Nam.

B. Regional and International Programs

1. International Agricultural Research Centers

International R&D programs using modern biotechnology are being conducted by the international agricultural research centers (IARCs), particularly the International Rice Research Institute (IRRI), International Maize and Wheat Improvement Center (CIMMYT), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International

Livestock Research Institute (ILRI), and International Service for National Agricultural Research (ISNAR). The Center for International Forestry Research also uses biotechnology in the characterization of forest diversity in its Asian program. The International Center for Living Aquatic Resources Management is using new technologies in the improvement of fisheries and aquaculture systems. ILRI is initiating a program on Asian livestock improvement. The CGIAR centers invest approximately \$30 million per year in modern biotechnology. Further details of the way the IARCs use biotechnology in their crop improvement programs are given in Appendix 11.

2. ISNAR Biotechnology Service

The ISNAR Biotechnology Service (IBS), with Japanese support, has been assisting selected Asian countries in developing human resources for managing biotechnology research programs or institutions. IBS has developed specialized courses to enhance the capacity and competency of managers, focusing on strategy building, priority setting, managing biosafety and regulatory aspects, resource generation and deployment, product delivery, and information sharing as well as the establishment and management of linkages.

3. International Service for the Acquisition of Agri-biotech Applications

The International Service for the Acquisition of Agri-biotech Applications (ISAAA) is brokering public-private sector partnerships to facilitate technology transfer. It has current regional projects to increase the productivity of maize, papaya, and sweetpotato. ISAAA is also establishing a new Asian knowledge center for crop biotechnology, based in the Philippines, in partnership with CAB International and the Southeast Asian Regional Center for Graduate Study and Research in Agriculture. Its purpose is to make available timely and balanced information on the risks and benefits of crop biotechnology to interested parties in Asia. In doing so, it aims to provide training and study tours highlighting experiences not only in research but also with biosafety and intellectual property issues.

C. Activities of Funding Agencies

The major external sources of assistance for agricultural biotechnology in the Asia/Pacific region are ADB, Australia, the Rockefeller Foundation, the United Nations, the United States Agency for International Development (USAID), and the World Bank.

1. Asian Development Bank

ADB has made several strategic and innovative investments in agricultural biotechnology over the past decade. These investments have been in the form of loans and technical assistance projects.

a. Components of Agriculture and Science and Technology Loan Projects

Several governments have requested ADB financial support for human resource development, laboratory facilities, and equipment for agricultural biotechnology programs. These programs have been integrating new applications of biotechnology into their conventional agricultural R&D programs. The applications include the use of new molecular diagnostics for pests and diseases and MAS for crop and livestock breeding. Such components are being supported under ongoing ADB projects in the Philippines, Sri Lanka, and Thailand (Table 3.2). ADB has provided other loans and grants in closely related areas such as in integrated pest management in cotton under the Cotton Development Project in Pakistan.

b. ADB Regional Technical Assistance Projects

ADB has provided regional technical assistance grants for the development of the three regional crop biotechnology networks over the past decade (Table 3.2). The networks are the Asian Rice Biotechnology Network (ARBN), initiated in 1993, the Asian Maize Biotechnology Network (AMBIONET), initiated in 1998 and the recently established Asian Semi-Arid Crops Network. These networks have been influential in developing capacity to use new techniques in crop breeding for the major cereal crops (rice, maize) and the crops important in the semi-arid regions (sorghum, pigeonpea, and groundnut). The networks are managed by three IARCs (IRRI, CIMMYT, and ICRISAT) that work with national re-

Table 3.1: Status of Agricultural Biotechnology

Country	Key Institution	Research Area
People's Republic of China	Institute of Biotechnology Research, Chinese Academy of Agricultural Science, China National Center for Biotechnology Development	Disease and insect resistance; tolerance for abiotic stress; product quality in rice, cotton, maize, wheat, and vegetables
India	Department of Biotechnology, Ministry of Science and Technology	Coordination of nationwide biotechnology activities; R&D in biofertilizers and bioinsecticides; nitrogen fixation; immunodiagnosics; genetic engineering; embryo-transfer Crops: rice, maize, cotton, citrus, coffee, mangrove, vanilla, and cardamom
Indonesia	Agency for Agricultural Research and Development, Center for Biotechnology Research and Development	Coordination of agricultural biotechnology; R&D in rice, cassava, maize, cotton, soybean; tissue culture; mycorrhiza; rhizobium; genetic engineering; biodiversity
Malaysia	National Biotechnology Directorate; Ministry of Science, Technology and the Environment	Tissue culture, embryo transfer; genetic engineering; value-added products; feed, edible fungal protein; diagnostics; biomass conversion Crops: rice, papaya, orchid, chili, rubber, and oilpalm
Pakistan	National Institute for Biotechnology and Genetic Engineering, Center of Excellence in Molecular Biology	Biopesticides, biofertilizers; molecular breeding; genetic engineering for crop improvement Crops: rice, cotton, and chickpea
Philippines	National Institute of Molecular Biology and Biotechnology	Nitrogen fixation; biofuel, food fermentation, antibiotics, diagnostics; plant cell culture; high value added products; genetic engineering Crops: rice, maize, coconut, mango, and papaya
Thailand	National Center for Genetic Engineering and Biotechnology	Coordination of biotechnology; biocontrol; DNA fingerprinting; genetic engineering Focus: rice, shrimp, cassava, dairy cows, fruits, and vegetables
Viet Nam	Institute of Biotechnology, National Center of Natural Science and Technology	Plant tissue culture; insect and disease resistance; tolerance for abiotic stress; genetic engineering Crops: rice, maize, potato, sweetpotato, cassava, soybean, sugarcane, and cotton

Sources: Zhang (2000), Sharman (2000), Dart et al (2001), Nair and Abu Bakar (2001), Zafar (2001), de la Cruz 2000), Tanticharoen (2000), Tuong-Van Nguyen (2000).

in Some Asian Countries, 2000

Biosafety Mechanism	Achievement
Biosafety regulations on GMOs approved in 1996	Transgenic cotton is grown over an area of 500,000 ha. About 50 genetically modified varieties have been approved for environmental release or small-scale field testing
Biosafety guidelines for transgenic seeds, plants, and plant parts developed	Field testing of some promising transgenic crops in progress
Biosafety guidelines and labeling regulations developed	Field testing of transgenic crops in progress
National Biosafety Law has been drafted, but it has yet to be approved by the Government	Good progress in developing transgenic rice, papaya, banana, orchids, pineapple, oilpalm, and rubber; field testing of papaya has been approved
Biosafety guidelines and regulations are being prepared	Concentrated mostly on traditional biotechnology
Biosafety guidelines for contained use and release of GMOs developed. Commercialization guidelines ready for approval	Field testing of transgenic crops in progress
Biosafety guidelines for laboratory and field trials developed	The application of biotechnology to develop new molecular diagnostics for diagnosis and control of virus diseases in shrimp has been successful; some transgenic crops (tomato, papaya, chili, pepper, and cotton) are undergoing field testing
Biosafety guidelines and regulations are being prepared	Still in the early stage of modern biotechnology development

Table 3.2: Summary of ADB-Funded
(\$'000)

Loan/ RETA No.	Project	EA
A. RETA		
1. RETA 5331	Establishment of Plant Biotechnology Research and Training	ICRISAT
2. RETA 5510	Establishment of the Asian Rice Biotechnology Network	IRRI
3. RETA 5667	Asian Rice Biotechnology Network – From Products to Impact	IRRI
4. RETA 5766	Application of Biotechnology to Maize Improvement in Asia	CIMMYT
5. RETA 5812	Asian Rice Biotechnology Network: Achieving Impact and Sustainability	IRRI
6. RETA 5945	Rapid Crop Improvement for Poor Farmers in Semi-Arid Tropics of Asia	ICRISAT
B. Loans		
1. 791-PAK	Cotton Development	MINFAL
2. 1535-SRI	Science and Technology Personnel Development	MOST
3. 1698-THA	Agriculture Sector Program	MOF
4. 1740-PHI	Grains Sector Development Program	MOF and DOA

ADB = Asian Development Bank, CIMMYT = International Maize and Wheat Improvement Center, DOA = Department of Agriculture, EA = executing agency, ICRISAT = International Crops Research Institute for the Semi-Arid Tropics, IRRI = International Rice Research Institute, MINFAL = Ministry of Food, Agriculture and Livestock, MOF = Ministry of Finance, MOST = Ministry of Science and Technology, R&D = research and development, RETA = regional technical assistance.

Source: Asian Development Bank (various documents).

Projects in Biotechnology

Approval Date	Grant/Loan Amount (\$'000)	Remarks
29 Apr 1989	1,250	A well equipped biotechnology laboratory was established at ICRISAT
21 Nov1992	900	An Asian Rice Biotechnology Network covering several Asian countries was established
9 Jan 1996	850	Further support to rice biotechnology was provided
29 Dec 1997	1,400	An Asian Maize Biotechnology Network covering some Asian countries has been established
22 Oct 1998	1,000	The third phase of rice biotechnology research is supported by ADB
17 Oct 2000	1,200	High-yielding varieties of groundnut, chickpea, and sorghum will be developed using marker-assisted selection
30 Sep 1986	66,100	Loan savings used to strengthen biotechnology R&D of cotton in Pakistan
11 Sep 1997	20,000	Part of the loan was used to expand science and technology personnel development and to strengthen the biotechnology research agency in Sri Lanka
23 Sep 1999	300,000	Some of the local currency of the loan was used to strengthen the biotechnology R&D in Thailand
24 Apr 2000	100,000	Part of the loan is being used to support rice biotechnology research in the Philippine Rice Research Institute

search institutes to implement the programs on rice, maize, and semi-arid crops.

A recent evaluation of ADB's research investments through the international centers reported favorably on the achievements of the rice and maize biotechnology networks, and recommended further support for this type of research cooperation.

The networks provide a platform by which countries and the IARCs can collaborate in the use of the new tools of functional genomics to identify genes that control important traits such as drought and salinity tolerance. This will speed up the breeding of crop varieties with these characteristics that have been difficult to address through conventional breeding. There will be increasing opportunities for cooperation between the networks, as more knowledge is gained on the commonality of genes between species and their control.

Box 3.1: Asian Rice Biotechnology Network

The rice growing countries in Asia recognized in the early 1990s that biotechnology could provide powerful new tools for rice improvement. These tools included tissue culture, wide hybridization, molecular markers, and genetic engineering. The ARBN was initiated in 1993 to provide a vehicle for collaborative research in these areas with universities and national rice research institutes.

The objectives of ARBN are to (i) promote human resource and infrastructure development for biotechnology at selected national agricultural research systems (NARSs) institutes through joint research and training coordinated by IRRI, and (ii) generate biotechnology tools and products for use by NARSs through IRRI research and infrastructure development.

ARBN was established with funds provided by ADB and the German Government's *Bundesministerium für Technische Zusammenarbeit*, which has been supporting IRRI's development of biotechnological products of direct use to NARSs. ADB supports research and infrastructure development at NARSs with additional funding for training and shuttle research by NARSs scientists at IRRI.

Box 3.2: Asian Maize Biotechnology Network

Member countries of AMBIONET are PRC, India, Indonesia, Philippines, and Thailand. The network was established in 1998 with financial support from the ADB. AMBIONET emphasizes developing molecular markers for specific traits and using them in the selection of new maize varieties. The goals of AMBIONET are to:

- increase the scientific capacity of Asian maize and biotechnology programs to ensure higher, more stable, and more sustainable maize productivity for farmers in Asia, and thereby help meet the region's rapidly growing demand for maize;
- develop sustainable, environmentally friendly, and natural resource conserving maize production systems;
- empower national programs to effectively use modern biotechnology for maize improvement;
- strengthen the ability of national programs to identify and overcome the key production constraints faced by maize farmers in the region; and
- generate and distribute improved maize cultivars, and implement improved crop management strategies, in collaboration with existing national program personnel, and by using facilities and other resources more effectively to avoid duplication; and ensuring the long-term sustainability of integrated maize and biotechnology research programs in participating countries.

2. Australian Government

Over the last 15 years, ACIAR has entered into more than 100 biotechnology R&D partnerships with at least 10 Asian countries in support of more than 600 active or completed projects. The emphasis of this work has been on developing diagnostics and vaccines for a large suite of diseases of tropical livestock, with some recent work on fish and shrimp being undertaken. Most of these projects have been implemented through government programs, but NGOs are becoming increasingly involved. Molecular marker methods for identifying disease-resistant genes and prolificacy in livestock have also been developed. Several projects on biotechnology for rumen manipulation have been carried out.

Crops and forestry work has focused on development of diagnostics for diseases (viral, fungal, mycoplasma, and bacterial) and contaminants in tropical crops, and the application of biofertilizers, bioremediation technology, and biofumigants. Molecular markers have been developed for the improvement of cereals and tree species. In cooperation with IRRI, attempts are being made to develop apomixis systems for rice. Tissue culture methods for micropropagation and conservation of several species, including sweetpotato, taro, tropical fruits, coconut, green tea, and tree species such as mangrove are being developed.

Eight of ACIAR's current or completed projects have included aspects of plant genetic engineering, with target crops being cereals and pulses, groundnut, and several tropical fruits. Target characters include virus resistance and quality defects related to ripening processes. These collaborative projects were developed at the request of the Asian countries, which fully approved regulatory procedures. ACIAR also provides core funding to many CGIAR and other IARCs, a proportion of which is applied to biotechnology R&D.

Australian support has been provided through AusAID for an Association of Southeast Asian Nations (ASEAN)/Australia regional biotechnology network, mainly concerned with food, microbial, and industrial biotechnology. AusAID also supports the characterization and conservation of genetic resources of taro and forest genetic resources in the South Pacific. AusAID has supported several biotechnology seminars. A major seminar in 1989 at the Australian Academy of Sciences on the potential of agricultural biotechnology in international development reported on the outcomes of a joint study cosponsored by AusAID, ACIAR, ISNAR, and the World Bank (Persley 1990a, 1990b).

In the area of human resources, the Crawford Fund has sponsored several master classes in biotechnology for senior policymakers over the past decade.

3. The Rockefeller Foundation

Operational from 1984-1999, the Rice Biotechnology Network sponsored by the Rockefeller Foundation was very active and successful in the region. The program's two objectives were to (i) to create biotechnology applications to produce improved rice varieties suited to developing country needs, and (ii) to train scientists in developing countries to use the techniques and adopt them to their own objectives. A network of about

200 senior scientists and 300 trainee scientists from all the major rice producing countries of Asia and a number of industrialized countries participated. The program was funded at approximately \$5 million per year for 15 years.

Another outcome of the program was the development of promising new technologies for the control of rice pests and diseases and improving the nutritional quality of rice. The work is being continued by national governments, ARBN, and IRRI to do the field evaluation and distribute new rice varieties in Asia.

The Rockefeller Foundation presently concentrates its biotechnology programs in Asia on drought tolerance in rice and maize. It is also examining innovative means of dealing with access to technologies and IP issues.

4. United Nations Agencies

The Food and Agriculture Organization (FAO) is giving high priority to biotechnology within its Asia/Pacific regional programs (FAO 2000). During 1989–1993, the United Nations Development Programme financed the establishment of biotechnology centers in eight countries (PRC, India, Indonesia, Republic of Korea, Malaysia, Pakistan, Philippines, and Thailand) to share rDNA techniques in animal improvement, embryo transfer, and disease control. In 1994 the United Nations Industrial Development Organization (UNIDO) established an International Center for Genetic Engineering and Biotechnology in New Delhi, India, to assist Asian countries in the applications of biotechnology to important crops of the region.

5. United States Agency for International Development

The USAID is supporting applications of biotechnology through bilateral activities in several countries, including India, Indonesia, and Pakistan. USAID is also providing specific support for biotechnology applications within the programs of IARCs. This includes support for research by IRRI on improving the nutritional quality of rice by increasing its vitamin A and iron content, and support for research by the Tata Energy Research Institute on the development of *golden* mustard.

6. World Bank

The World Bank has supported the development of infrastructure and human resource development for biotechnology in several Asian countries over the past 15 years. This support has come through loans in the agricultural sector, science and technology, and education. There are currently substantial components for biotechnology within agricultural technology projects in India, Indonesia, and Pakistan. The Inter University Centers for Biotechnology in Indonesia were built with a \$150 million loan in the 1980s. The Republic of Korea also used World Bank loans to develop its infrastructure in biotechnology. The World Bank is also one of the main financial supporters of CGIAR centers. The centers invest about 10 percent of their total annual budget of \$340 million in the applications of biotechnology.

IV RISK ASSESSMENT AND MANAGEMENT

A. Public Perception of Risks

As with any science and technology, biotechnology can bring with it benefits and risks. It is the risks of agricultural biotechnology that have received widespread publicity in the media even though biotechnology has also been applied to health and industrial sectors. Environmental NGOs have been particularly vocal in taking issue with the new technologies derived from or incorporating GMOs. As a consequence, in the public debate biotechnology has become synonymous with GMOs, although they are only one of the many products of biotechnology.

Curiously, biotechnology and GMOs in health-care products now in widespread use (insulin, hepatitis vaccine, medication for cardiovascular disease, etc.) or for industrial purposes such as bioremediation have elicited no such controversy. This can probably be attributed to the lack of benefits to consumers in the first generation of genetically modified (GM) crops. The main focus was on herbicide and insect resistance that benefited farmers, seed producers, and chemical companies. It is expected that the next generation of genetically modified foods will benefit consumers, nutritionally or from taste or storage benefits, and accordingly may be better accepted.

A number of food-related crises in recent years have made consumers particularly sensitive about food safety issues. Health and food safety concerns are again at the forefront in Europe following additional cases of mad cow disease (*bovine spongiform encephalopathy*) and the banning throughout the European Union of blood and bone meal in feed for all animals. These crises have not been caused by GMOs, but by the intensification of agriculture and food production, a fact that appears to have escaped public attention. In Europe in particular, demands have been made for informative food labeling so that consumers may, if they wish, avoid genetically modified foods.

The anti-GMO movement reveals profound mistrust of developments in science and technology and of the forces seen to be driving them. Genetically modified crops such as maize, sorghum, cotton, and canola have been widely grown for the last five years, yet no harmful effects on human health or the environment have been detected. That was

one of the conclusions of the OECD-sponsored conference held in Edinburgh, UK, in 2000. However, it is generally agreed that government and the private sector are responsible for monitoring the long-term effects of GMOs on human health and the environment.

B. Potential Risks of Biotechnology

The risks associated with modern biotechnology fall into four categories: food safety, environmental, socioeconomic, and ethical (Table 4.1). Some of these concerns relate to potential risks inherent in modern biotechnology and can be described as technology-inherent (Leisinger 2000). Others are related more to value systems or cultural practices and can be described as technology-transcending.

1. Food Safety Concerns

The potential risks of biotechnology on human health may include toxic reactions, increased cancer risks, food allergies, food contamination, and antibiotic resistance (Table 4.1). There is also concern that GMOs in animal feed might present a health risk for consumers, or for the animal itself. Consumers are also concerned about the long-term health effects of genetically modified foods.

To address food safety concerns, the following safeguards have been adopted by some countries:

- (i) Some countries have regulatory procedures, institutions, and infrastructure in place to ensure food safety (OECD 2000). These regulations cover all aspects of the food chain, from farm inputs (including animal feed, feed additives, pesticides, fertilizers, veterinary drugs) through production and processing (including agricultural products, processed food, novel foods, food additives), to transportation, storage, and distribution.
- (ii) Formal science-based procedures for risk analysis of food have been adopted by some countries. These continue to evolve with new scientific information about food safety, emerging pathogens, new technology, and consumer demands for a high level of public health protection. Generally,

Table 4.1: Summary of Perceived and Genuine Risks of Genetically Engineered Foods and Crops

Nature of Risk	Type of Risk	Remarks
Food Safety	1. Toxins and poison. In 1998, a scientist in the Rowett Institute found that GE potatoes spliced with DNA from the snowdrop plant (a viral promoter) are poisonous to mammals.	The UK Government's Advisory Committee for Novel Food and Process examined the data and concluded that the experiment was faulty and the conclusions were wrong.
	2. Increased cancer risks. Monsanto's bovine somatotrophin (growth hormone) injected into dairy cows to produce more milk has been reported to cause cancer in human breast, prostate, and colon.	This is not a GM food. In any event, Canada and the European Union have banned its use. A United Nations Food Standard body has not certified its safe use. The hormone is no longer widely used in US.
	3. Food allergies. In 1996, a Brazil nut gene spliced into soybean was reported to induce potentially fatal allergies in people sensitive to Brazil nuts.	The safety assessment confirmed that the protein was an allergen and the development was abandoned. A standard laboratory test has been available to test possible allergenicity in GE products.
	4. Contamination. StarLink, a GE maize variety approved for animal feed but not for human consumption, was found in an ingredient used by some US beer makers and in taco shells in the US in 2000.	The incident was caused by an accidental mix of StarLink with vast amounts of other maize during harvest, storage, and distribution. The contaminated food was recalled and destroyed. A number of quick and cheap tests are available to determine the presence of GM products in food.

Table 4.1: Summary of Perceived and Genuine Risks of Genetically Engineered Foods and Crops (cont'd.)

Risks	Type of Risk	Remarks
Environmental Risks	5. Antibiotic Resistance. Use of an antibiotic marker gene in the development of GE crops may contribute to the growing public health danger of antibiotic resistance.	There is little or no evidence about this risk yet. But this is an emotive topic, and developers have now replaced the antibiotic marker with a safer marker.
	1. Increased pesticide residues. Farmers growing GE crops will use as many toxic insecticides and herbicides as conventional farmers, thus increasing pesticide residues in soils and on crops.	This risk is not yet proven statistically. There are reports that farmers growing GE crops resistant to pests and herbicides are able to reduce production cost significantly through the reduced use of pesticides. That was a major reason why farmers adopted GE crops widely in the PRC and the US.
	2. Genetic pollution. Wind, rain, birds, and bees have carried genetically altered pollen into adjoining fields, contaminating the DNA of organic, non-GE crops.	This genetic pollution is not an environmental issue unless the transfer of pollens causes some kind of environmental damage. Pollen contamination has taken place for centuries with or without genetic engineering.
	3. Damage to beneficial insects. Scientists from Cornell University found that pollen from Bt maize was poisonous to Monarch butterflies and may be to other beneficial insects as well.	Monitoring systems have been devised in the PRC and the US to evaluate the long-term effect of GE crops on beneficial insects.

Table 4.1: Summary of Perceived and Genuine Risks of Genetically Engineered Foods and Crops (cont'd.)

Risks	Type of Risk	Remarks
	4. Creation of superweeds. GE crops (soybean and canola) resistant to herbicides may transfer their resistance to weeds, turning them into superweeds, which cannot be controlled by herbicides.	This fear has yet to be proven. Scientists are closely monitoring the use of GE crops resistant to herbicides.
	5. Creation of superpests. GE crops (maize and cotton) resistant to pests may transfer their resistance to pests, turning them into superpests which cannot be controlled by pesticides.	As above, this fear has yet to be proven in practice. There is no known mechanism by which pest resistance from a plant may be transferred to an insect pest.
	6. Creation of new viruses and bacteria. Biotechnology could help terrorists to create killer viruses or bacteria, which could be used in biological weapons.	This could happen, even without biotechnology. Terrorists historically have managed to acquire and subvert beneficial technologies to antisocial purposes.
	7. Genetic bioinvasion. By virtue of their superior genes, some GE plants and animals will inevitably run amok, overpowering wild species in the same way that introduced exotic species do.	There is as yet no scientific evidence that such plants and animals can be created through biotechnology.

Table 4.1: Summary of Perceived and Genuine Risks of Genetically Engineered Foods and Crops (cont'd.)

Risks	Type of Risk	Remarks
Socioeconomic Risks	1. Terminator technology will render seeds infertile and force hundreds of millions of farmers to purchase more expensive GE seeds and chemical inputs from a handful of global biotechnology and seed companies.	The Monsanto Company has withdrawn the terminator gene from its GE crops following many complaints from farmers.
	2. High concentration of biotechnology research and development in developed countries will widen the income disparity between developed and developing countries, and between large and small farmers.	The public sector in Asia should accord high priority to biotechnology development that address the problems of small farmers.
Ethical Concerns	1. Biotechnology reduces all life to bits of information (genetic code) that can be rearranged at whim by scientists. The creation of the first genetically modified monkey in 2000 brings the possibility of genetic manipulation closer to humans. There is fear that the technique will be used to create "designer babies."	Although most of these ethical concerns relate to non-agricultural biotechnology, they point to the need for the private sector to incorporate work ethics in biotechnology research and development.
	2. There seems to be little ethical concern by the private companies over the use of GE animals to produce therapeutic drugs.	

Bt = *bacillus thuringiensis*, DNA = deoxyribonucleic acid, GE = genetically engineered, GM = genetically modified, PRC = People's Republic of China, US = United States.

Source: Skerritt (2000) and Wolfenbarger and Phiher (2000).

the procedures conform to international standards set by the Codex Alimentarius Commission of FAO.

- (iii) Some countries have adopted a variety of approaches to regulate genetically modified foods, either by applying existing food safety measures or enacting new legislation.
- (iv) In response to consumer demands, a growing number of countries are introducing labeling. Opinions differ on whether labeling should be mandatory or voluntary, as well as on acceptable tolerance levels and on the type of information to be used. Two labeling issues currently being addressed are segregation and traceability. Segregation relates to the ability to attest to the separation of genetically modified and non-genetically modified crops (as in the case of soybean in processed foods). Traceability means being able to attest to the origins of food products. Traceability is of particular importance in the current controversy related to mad cow disease. Low cost, quick tests are now available to determine the presence of genetically modified products in food.

2. Environmental Concerns

A number of biotechnology applications are not seen to present any new threats to the environment. That is the case with tissue culture, diagnostics, and market-selected plant breeding. On the other hand, there is fear of potential risks from the release of GMOs into the environment. The potential risks of GMOs on the environment may include increased pesticide residues, genetic pollution, damage to beneficial insects, creation of superweeds and superpests, creation of new viruses and bacteria, and genetic bioinvasion (Table 4.1).

To address environmental concerns, some countries have adopted the following safeguards:

- (i) Most current biotechnology applications in tissue culture and micropropagation, diagnostics and vaccines, and marker-assisted plant breeding are subject to existing regulations. They include phytosanitary regulations and plant quarantine, varietal certification of seeds, and veterinary product regulations. These regulations usually conform to international standards, guidelines, or recommendations such as those set

- by the International Plant Protection Convention or the International Bureau of Epizootics for animal products.
- (ii) A number of countries have introduced new requirements and procedures for the environmental release of GMOs. Procedures for hazard identification and risk assessment of GMOs are now well-established in most OECD countries, and in some Asian countries.

3. Socioeconomic Concerns

Modern biotechnology R&D has been conducted in an institutional and economic environment that differs significantly from the development of the earlier Green Revolution technologies. While the latter were essentially the prerogative of public research institutions and philanthropic foundations, developments in biotechnology have been driven essentially as a competitive, commercial endeavor in which powerful private sector actors compete.

The major socioeconomic risk of agricultural biotechnology stems from the fact that the research, development, commercialization, and distribution of new biotechnological products have been carried out mainly in developed countries by a few, large, multinational companies. These companies have focused on temperate crops for large farmers in developed countries. Undertaking R&D on Asia's basic food crops for small farmers in rainfed and marginal areas is of little interest because they see limited returns from such investments (see detailed discussion on this issue in Chapter II, section C). If this trend continues, modern biotechnology will aggravate the income disparity between developed and developing countries, and between large and small farmers. Increased public investments in agricultural biotechnology are necessary to ensure that small, poor farmers have access to biotechnology. Governments must also address the potential gender disparity in the access to technology, and the negative impact specific to women, since no technology is gender neutral. Lessons from earlier agricultural technological changes should be used as a caveat.

4. Ethical Concerns

Ethical issues may stem from the uneven or inequitable impact of an expanding global economy; from the national social, economic, and politi-

cal context; or from individual values. Indeed, it may be difficult to reconcile personal values with what a majority regard as the common good.

One of the ethical concerns raised by biotechnology—and particularly GMOs—is that it is unnatural and an unwarranted tampering with nature. However, seen in historical perspective, most technology developments in agriculture over the centuries have involved, in one way or another, efforts to overcome the vagaries of nature.

C. Risk Management

To address the potential risks of biotechnology in agriculture, there is a need for Asian countries to establish effective biosafety procedures for the development, testing, and release of the technologies. An example on how this should be done is shown in Figure 4.1.

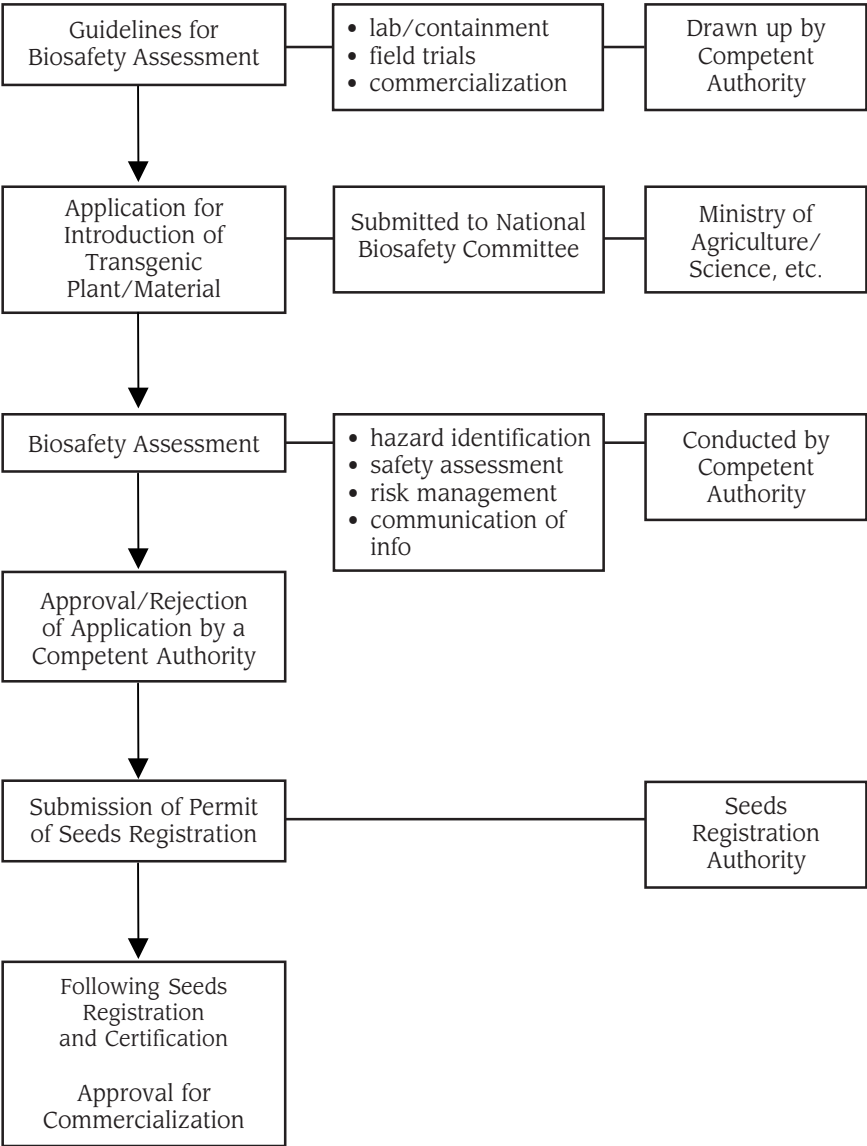
1. Current and Emerging Regulatory Systems for Biotechnology

A growing number of international organizations have become involved in food and environmental safety. Concerted international efforts to develop agreed upon scientific approaches to biosafety date from 1975, when a group of scientists from the United States National Academy of Sciences expressed concern regarding the potential biological risks of rDNA molecules. Efforts to ensure the science-based, case-by-case risk identification, assessment, and management of GMOs have thus been pursued for some 25 years.

In the industrialized world, OECD has been instrumental in forging agreements on scientific principles regarding the safe applications of rDNA organisms in industry, agriculture, and the environment. Since the 1980s, OECD has established guidelines, first for (i) laboratory-based experimentation, then (ii) for small- and large-scale field trials of genetically modified plants and organisms, and finally (iii) for their commercialization and release into the environment or food chain.

During the 1990s, a growing number of international organizations including the United Nations Environmental Programme (UNEP), UNIDO, World Health Organization (WHO), and FAO have become involved in activities related to biosafety. Both UNIDO and UNEP have developed biosafety guidelines. FAO and the WHO are jointly responsible for the Codex Alimentarius Commission, which sets international standards for

Figure 4.1: Procedures for Release/Commercialization



food safety. Codex has set up a new Intergovernmental Task Force on Foods Derived from Biotechnology to develop general principles for risk analysis and to provide guidance on risk assessment.

Other international organizations conducting work on the safe use of biotechnology include the International Centre for Genetic Engineering and Biotechnology, the United Nations Conference on Trade and Development, and, for many aspects of animal as well as human health, the International Bureau of Epizootics.

2. The Convention on Biological Diversity and the Cartagena Biosafety Protocol

Preoccupation with the protection of biological diversity, necessary for sustaining agriculture and food production and, indeed, life itself, became a topic of international debate during the 1980s. As a result, FAO established the International Undertaking on Plant Genetic Resources as a nonlegally-binding agreement for cooperation in the conservation of genetic material. The agreement was based on the universally accepted principle that plant genetic resources are a heritage of mankind and consequently should be available without restriction. The legally binding Convention on Biological Diversity, which came into force in 1993, encompasses not only plant genetic resources but all living organisms. In contrast to the FAO undertaking, the Convention affirms that States have sovereign rights over their own biological resources.

In January 2000, the legally binding Cartagena Protocol on Biosafety was adopted. This Protocol lays the foundation for a global system for assessing the impact of GMOs on biodiversity. It outlines the obligations of all countries that are signatories to protect biological diversity from the potential risks imposed by living modified organisms resulting from modern biotechnology.

At the heart of the Protocol is the concept of advanced informed agreement to the import of GMOs. This means that an exporting country must inform an importing country of its intention to export. It must also provide information on the GMOs, including an appropriate risk analysis. For its part, an importing country is required to give its informed agreement to the import. This implies that, although signatory states have the right to prohibit the import of GMOs if advanced informed agreement has not been given, they must also be capable of determining the validity of a safety assessment.

In addition, the Protocol advocates the “precautionary approach,” described in the 1992 Rio Declaration on Environment and Development as a principle of international environmental law. The Protocol also proposes to establish a Biosafety Clearing-House for collecting, sharing, and disseminating information on risk assessment and management, which is particularly important for developing countries. Thus far, 81 countries have signed the Protocol, including Bangladesh, PRC, Indonesia, Republic of Korea, Malaysia, Philippines, and Sri Lanka.

3. Approaches in Selected OECD Countries

A sample of industrialized countries shows a diversity of approaches to food and environmental safety and in the agencies or ministries that play key roles in the national biosafety system. For example, the US has chosen to develop biosafety capacity within existing institutions (notably the Environmental Protection Agency and the Department of Agriculture). Denmark has designated the National Forest and Nature Agency as the lead agency for biosafety. In Norway, in accordance with the Gene Technology Act, the application of GMOs is subject to ethical and social conditions. A GMO can be approved for use only after the assessment of its benefit to the community and its contribution to sustainable development.

In Australia, apart from the different ministries involved, an Advisory Committee on Genetic Engineering was created some years ago. That will soon be replaced by an office with an enforcement rather than an advisory role. A public hearing must be held before authorization is given to release a GMO. Australia has recently created the Office of the Gene Technology Regulator to operate in the Commonwealth Department of Health and Aged Care.

Japan has based its risk assessment system on the principles and concepts developed by OECD. Different Japanese ministries and agencies have developed guidelines in accordance with their responsibilities on a product-sector basis.

A growing number of countries are introducing guidelines or mandatory measures for labeling genetically modified foods. In the US, formerly strongly opposed to labeling, the Food and Drug Administration has recently been charged with developing guidelines for voluntary labeling of food products to indicate whether or not they contain GMOs. In the European Union, food products containing more than 1 percent GMO must be labeled, stating clearly: “this product contains GMOs.” The Australia-

New Zealand Food Standards Council is drawing up a new Food Standards Code. Labeling requirements will be drawn up in accordance with this joint Code. Japan is planning the introduction of mandatory food labeling in April 2001.

The OECD has also played an active role in promoting the harmonization of biosafety procedures among its member countries so that information and data gathered in the course of risk assessment may be mutually acceptable.

4. Emerging Regulatory Systems in Asia

Table 4.2 indicates the status of regulatory systems in a number of Asian countries. A growing number have set up national biosafety systems; others are formulating national biosafety guidelines. Most countries have not yet completed guidelines for commercialization. The PRC is the only country in Asia where transgenic crops have been approved and released for sale. A number of countries are also in the process of introducing food labeling. Indonesia is planning to introduce mandatory labeling in April 2001.

ASEAN has undertaken a number of initiatives aimed at the harmonization of biosafety procedures among its member countries. In 2000 it also conducted a joint workshop with the Ministry of Science and Technology of the PRC to discuss issues related to transgenic plants.

The Asia-Pacific Economic Cooperation has a number of capacity-building and technical cooperation activities in support of risk assessment, risk management, risk communication, and public acceptance. Responsibility rests with its Agricultural Technical Cooperation Experts Group and its Sub-Group on Research, Development and Extension of Agricultural Biotechnology.

Although some Asian countries have regulations in place, weak law enforcement sometimes results in the release of GMOs without proper procedures having been followed. For example, P.T. Monagro Kimia (a subsidiary of Monsanto) released Bt cotton in Indonesia without complying with Indonesian environmental law on safety procedures, environmental assessment, and information disclosure. Law enforcement in Asia needs strengthening to avoid risk to human and environmental health.

Table 4.2: Status of Biosafety in Selected Asian Countries

Country	Responsible Ministry/Agency	Status of Regulatory System			
		Regulatory System in Place	rDNA/ Lab Testing	Field Testing GMOs	Commercialization
China, People's Rep. of	<ul style="list-style-type: none"> Ministry of Agriculture (Safety Administration Office for Agricultural Biological Genetic Engineering) Ministry of Public Health 	X	X	X	X
India	<ul style="list-style-type: none"> Ministry of Science and Technology (Department of Biotechnology) Review Committee on Genetic Manipulation Ministry of Environment and Forests (Genetic Engineering Approval Committee) Monitoring and Evaluation Committee 	X	X	Field testing approved	
Indonesia	<ul style="list-style-type: none"> Ministry of Agriculture (Agency for Agricultural Research and Development) Biosafety and Food Safety Commission 	X	X	X	
Malaysia	<ul style="list-style-type: none"> Ministry of Science, Technology and Environment Genetic Modification Advisory Committee Department of Agriculture 	X	X	Field testing for papaya approved	
Thailand	<ul style="list-style-type: none"> Ministry of Agriculture and Cooperatives Department of Agriculture/National Center for Genetic Engineering and Biotechnology National Science and Technology Development Authority 	X	X	X	
Philippines	<ul style="list-style-type: none"> National Committee on Biosafety Department of Science and Technology 	X	X	X	Guidelines for plants and plant products ready for approval

Note: X indicates that the countries have complied with the requirements.
Source: Consultants' assessment.

D. International and Donor Support for Biosafety Capacity Building in Asia

A growing number of initiatives are being taken to provide support for Asian countries in developing their capacities to safely manage biotechnology. A representative sample follows.

Following the signing of the Biosafety Protocol, UNEP, through its Global Environment Fund, is preparing a major capacity-building program for developing countries. It will also be responsible for the establishment of the Biosafety Clearing-House.

FAO serves as the secretariat for the International Plant Protection Convention, which has recently established a working group on the Phytosanitary Aspects of GMOs, Biosafety and Invasive Species.

UNIDO has conducted training courses in biosafety in a number of Asian countries. In collaboration with OECD, it has compiled an information source and database (BIOBIN), which provides information on biosafety methods and procedures, and on the status of the regulatory frameworks in individual countries.

OECD has established a network of international organizations with activities related to biosafety to enhance the exchange of information and to facilitate cooperation.

IBS provides a number of services to enhance developing country capacities to manage agricultural biotechnology. It gives short training courses annually for managers of agricultural biotechnology research programs in Asia. Biosafety is a key element in these courses. IBS also provides advice to individual countries.

USAID is involved in a number of biosafety training activities in Asian countries, some of which have been provided by its Agricultural Biotechnology Services Program.

ISAAA is currently setting up a Global Knowledge Center on Crop Biotechnology based at ISAAA's SEAsia Center at Los Baños in the Philippines. ISAAA also organizes capacity-building workshops and training for regulatory officials and scientists from the Asian region.

E. Genetically Modified Organisms: Food and Environmental Issues

In industrialized countries, considerable progress has been made in methods, approaches, and experience in the safe management of GMOs. Overall these methods have proven to be effective, particularly with respect to food safety. The development of a transgenic soybean containing a protein derived from Brazil nuts, potentially useful in animal feed, was abandoned when the safety assessment revealed that the protein was probably an allergen. In response to consumer concerns, antibiotic markers are now being phased out as alternatives are being developed. That despite consensus among national and international regulatory authorities and the scientific community that the markers pose no threat to human health.

Despite acknowledged progress, areas of scientific uncertainty or disagreement persist. New challenges for risk/safety assessment, management, and monitoring will arise as a second generation of food, agricultural, and public health products emerges during this new decade.

Not only are the ranges of organisms and numbers of traits expected to expand, so are the numbers and diversity of geographic and ecological sites in which they are released. These new products will not lend themselves easily to current approaches and methods to risk and safety assessment and to management. This highlights the need for constant review and improvement of assessment principles and procedures, and the urgent need for collection and analysis of ecological data.

Other areas where consensus has not been reached among scientists themselves, or among scientists and policymakers, include (i) the precautionary approach as a method of dealing with scientific uncertainty, and (ii) methods for traceability.

The potential for the development of insect resistance to Bt transgenic crops is another area where the scientific community, industry, and environmental NGOs have not reached consensus. Risk management approaches at the farm level have so far been applied mainly on large-scale, commercial farms where monoculture is practiced. The same approaches may not be effective and, indeed, may not be necessary in the mixed farming systems of Asia.

Efforts to address the issue of resistance to transgenic crops have recently been initiated in Asia. A first International Consultative Workshop on Effective and Sustainable Use of Agricultural Biotechnology in

Integrated Pest Management in Developing Countries was held in November 2000. Organized by IRRI, Zhejiang University, and the International Organization for Biological Control, the workshop tried to determine strategies for the safe deployment of crops such as cotton and rice with novel Bt genes for pest resistance.

Among OECD countries, the continued monitoring of GMOs after release into the natural environment is also an area where opinions differ. On the one hand, it is argued that monitoring should be continued so that unforeseen risk can be managed and ecological impacts can be assessed. On the other hand, it can be argued that the high costs of monitoring are not justified when transgenics have already successfully passed the hurdles of risk identification, safety assessment, and risk management.

It is clear that the potential risks of GMOs may vary by site and over time. Continued research will be necessary to improve data collection and analysis and to modify or devise new risk management strategies as needed.

F. Future Perspective

To date, a number of Asian countries have made substantial investments in biotechnology R&D initiatives. Some public research institutions have reached the stage of field testing of new crop varieties, major research projects are coming to fruition in IARCs in the region, and private companies are also conducting research in the region, or have products waiting to be commercialized and exported to the region. It will be necessary to have biosafety procedures in place to ensure that the benefits of these technologies are realized.

Although many opportunities exist, from donor and other development agencies, in support of capacity building for the safe management of biotechnology, and in setting up national systems, it is the responsibility of national governments to ensure that national regulatory systems are applied, enforced, and monitored. Setting up an effective national regulatory system for the safe management of biotechnology requires substantial resources, both financial and human. It is also a political process and, as such, requires political commitment.

The Cartagena Biosafety Protocol confers both rights and obligations on countries that are signatories. A country is free not to allow the import of GMOs on its territory. At the same time, it has an obligation to

establish a national biosafety system. This means that even if a country decides to ban the import or use of GMOs on its national territory, it will still need to comply with the obligation to develop a biosafety system for the control of such organisms. It is anticipated that UNEP, the World Bank, and United Nations Development Programme (UNDP), through the Global Environment Fund, will contribute funding and technical assistance to developing countries for capacity building in biosafety. Even so, compliance with both the provisions of the Convention on Biological Diversity and the Cartagena Biosafety Protocol will place a heavy burden on some countries.

Apart from obligations under the Biosafety Protocol, if countries wish to control the import or introduction of GMOs on national territory, it will be necessary to have the means of detection in place. Similarly, from the perspective of international trade, when countries export agricultural or food products to countries that either prohibit the import of GMOs or require mandatory labeling for food or food products containing GMOs, the requisite regulatory procedures need to be in place.

The regulatory framework for biotechnology should not, however, be regarded in isolation from the broader policy context of agriculture and the contribution that biotechnology might make in the particular economic, social and environmental context of individual countries. Countries have a range of options in determining policies and priorities for biotechnology. These might range between active promotion of biotechnology approaches, "wait and see," or rejection. Similarly, countries have a range of options in designing and implementing a national biosafety system geared to their particular technical, legal, and institutional realities. For example, a complex and time consuming regulatory system might impose prohibitive costs for local enterprises, particularly start-up companies.

PRC is the only Asian country so far with experience of managing and monitoring new transgenic crops in the field on a large scale. Some countries are gaining experience in field testing, while others have not yet completed biosafety guidelines. Information on socioeconomic and scientific developments in biotechnology and biosafety can be accessed from a number of information sources, including the Biosafety Clearing House mechanism to be provided under the terms of the Cartagena Biosafety Protocol. These sources are especially important for countries such as Cambodia, Lao PDR, and Viet Nam.

V USING BIOTECHNOLOGY TO ADDRESS POVERTY REDUCTION AND FOOD SECURITY PROBLEMS IN ASIA

A. Linkage Between Biotechnology and Poverty Reduction and Food Security

Agricultural biotechnology will contribute to poverty reduction and food security if scientists can develop technologies to increase quality and yields of food crops, and the technologies are adopted by small farmers. For this to happen, biotechnology R&D will have to meet four conditions:

- (i) It must address both the problems of small farmers in rainfed areas where most of the poor live, and those of small farmers in irrigated areas, which provide the bulk of food grain supply in Asia.
- (ii) It must focus on crops, livestock, and fish commonly grown by small farmers. Major crops are rice, tropical maize, wheat, sorghum, millet, banana, cassava, groundnut, oilseed, potato, and sweetpotato. Biotechnology R&D should also focus on high value cash crops (e.g., cotton, soybean, and vegetables) that can increase the incomes of small farmers through crop diversification. The prospect for improving these crops is bright due to the large demand for them in urban areas and in international markets. Fish and livestock (cattle, sheep, goats, pigs, and chickens) are also important.
- (iii) The technology to be developed and delivered to small farmers must be simple, low cost, and carry little or no risks to human health and the environment. As in the case of the Green Revolution, the most effective strategy to increase food production is through improved seeds that possess high yield potential, fertilizer responsiveness, resistance to pests and diseases, good agronomic characteristics, and good nutritional quality.
- (iv) Biotechnology development should be accompanied by favorable policy environment; good governance; investments

in rural infrastructure; agricultural research and extension; and credit and marketing.

B. Why Invest in Agricultural Biotechnology?

In much of Asia, yields of major food grains are stagnant or declining in the face of population increases. Pests and diseases cause substantial preharvest and postharvest losses of crops, livestock, and fish. Solutions to many of these problems may lie in the various applications of modern biotechnology.

The use of molecular markers to tag specific traits is accelerating the breeding of new varieties of plants and animals. New understanding of plant and animal genes through genomics may offer ways of increasing crop yields.

These new developments when used in conjunction with developments in the physical and social sciences, offer more sustainable means for obtaining necessary productivity increases that are less dependent on environmentally damaging inputs of chemical fertilizers and pesticides. Given appropriate policies and necessary human and financial resources, modern biotechnology could make an extremely important contribution to future agricultural growth.

During the next 25 years, Asia will need a Second Green Revolution, often called Biorevolution or Doubly Green Revolution. Conway (1997) pointed out that the next technology-driven revolution must be doubly green—it must increase food production at a faster rate than in recent years without significantly damaging the environment. It must also increase incomes and increase access to food by the poor. The differences between the Green Revolution and Biorevolution are described in Table 5.1. Compared to the Green Revolution of the 1970s, Biorevolution will be characterized by the following features:

- (i) Potentially many crops (particularly high value and specialty crops), will be affected as well as livestock and aquaculture.
- (ii) Potentially all areas, both irrigated and rainfed, will benefit from biotechnology R&D.
- (iii) Technology development and dissemination will substantially involve the private sector with the public sector playing the role of facilitator and regulator.

- (iv) Many processes and products will be patentable and protectable.
- (v) Capital costs of research will be high.
- (vi) Molecular and cell biology expertise will be required in addition to expertise in conventional plant breeding and other agricultural sciences

Modern biotechnology (genetic engineering) is not a silver bullet for achieving food security, but used in conjunction with other techniques it may be a powerful tool in the fight against poverty and food insecurity (Persley and Lantin 2000). Other approaches are available and should be used. Narrowing the yield gap between those obtained from farmers' fields and those from experiment stations using the current technologies is just one example. However, there is concern that some conventional alternatives will not be able to produce the desired results within a limited time. The advantage of modern biotechnology rests on the speed at which desired crop varieties are produced. In some cases, the desirable genetic combination of traits is simply not possible through common breeding methods, and can be done only through genetic engineering.

To increase food production by at least 40 percent within the next 25 years, Asian countries not only have to move toward the best technological frontier (to push farmers' yields to the optimum level), but keep moving the technological frontier itself. As long as product safety, environmental and ethical concerns, and IP issues are adequately addressed, modern agricultural biotechnology has the potential to significantly increase the quantity and quality of the food supply for developing countries.

C. Applying Biotechnology in Resource Poor Areas

The resource-poor, rainfed areas in Asia are home to many poor people, and their population is growing rapidly. Although migration may sometimes be the only viable livelihood strategy, in many such areas sustainable intensification of agriculture may be the best way to achieve poverty reduction and food security. Development policy has often neglected these areas characterized by poor soils, shorter growing seasons, lower and uncertain rainfall, and little infrastructure or access to markets. Yield increases usually lag behind population growth. Efforts by poor farmers to expand cultivation onto new lands to eke out survival often

Table 5.1: Characteristics of the Green Revolution and the Biorevolution

Characteristics	Green Revolution	Biorevolution
Crops affected	Mainly wheat and rice	Potentially all crops, including cereals, vegetables, fruits, export commodities, and specialty crops
Other products affected	None	Animal and fish products Processed food products
Areas affected	Irrigated and other favorable areas	Potentially all countries and all areas, including marginal lands
Technology development and dissemination	Largely public or quasi-public sector	Substantial private sector involvement
Proprietary considerations	Patents and plant variety protection not important	Many processes and products patentable and protectable
Capital costs of research	Relatively low	Relatively high
Research skills required	Conventional plant breeding and other agricultural sciences	Molecular and cell biology expertise plus conventional plant breeding skills and expertise in other agricultural sciences
Crops displaced	None, but traditional varieties and land races replaced by high-yielding varieties	None, but traditional varieties and land races replaced by high-yielding varieties
Access to information	Relatively easy	Restricted due to IPR

IPR = intellectual property right.

lead to deforestation and erosion of fragile highland soils. That in turn threatens hydropower, road, and irrigation infrastructure in the lowlands. Policies and investments are required that can achieve food security in ways that protect natural resources, thereby breaking the vicious cycle of poverty, low productivity, and environmental degradation. Creation of nonfarm, rural jobs will also be important (ADB 2000b).

Sizeable investments in biotechnology in Asia have been made in rainfed areas, although DMCs continue to give high priority to irrigated agriculture. Irrigated areas produce 75 percent of total cereal production in Asia. Many IARCs such as the Asian Vegetable Research and Development Center, CIMMYT, CIP, ICRISAT, ILRI, and IRRI; and most DMCs have invested heavily in R&D on orphan crops such as rice, tropical maize, sorghum, potato, banana, groundnut, and sweetpotato.

D. Applicability of Biotechnology to Specific Agricultural Objectives

In Asia, biotechnology has been applied mainly to develop improved varieties adapted to specific environments. Specific areas where new applications of biotechnology could address poverty reduction and food security are summarized as follows:

- (i) **Increasing Productivity and Stability of Crops in Rainfed and Marginal Environments.** Producing more food on the same area of cultivated land would reduce pressure to expand cultivated areas to forests and marginal areas. Broadening tolerance of existing HYV cereals for drought, flooding, salinity, heavy metals, and other abiotic and biotic stresses would increase yields in rainfed areas. CIMMYT and IRRI, in cooperation with NARSs in different countries, are focusing their efforts to develop HYVs of rice and maize for rainfed areas.
- (ii) **Improving Water Use Efficiency in Crops.** Future availability of water for agriculture is a major issue. By 2020, there may be a water crisis in Asian agriculture (ADB 2000c). Crops with higher water use efficiency and tolerance for drought would be an advantage. With the completion of the rice genome, scientists will be able to identify genes responsible for drought tolerance.

- (iii) **Integrated Pest Management (IPM) Strategies to Reduce Pesticide Use.** The insecticides now used in many developing countries are often older, broad spectrum, acutely toxic compounds. Many are now banned in industrial countries except for export. They are a significant health hazard to farmers and farm workers throughout Asia. Over 80 percent of total pesticide use in Asia is on cotton, rice, and vegetables.

In the past, governments encouraged the use of chemical pesticides as part of a yield-increasing package of farm inputs, and some governments still subsidize pesticides. The need is now recognized for more sustainable approaches to IPM to reduce losses to pests without harmful side effects on human health and the environment. New pest- and disease-resistant crops, produced with the aid of modern biotechnology, may be important components of IPM strategies (Persley 1996).

Early applications are being seen in the use of novel sources of resistance (Bt genes) to control insect pests on maize and cotton. New pest-resistant cotton varieties are being grown widely in the PRC by 3 million farmers covering 500,000 ha (Pray 2000). Similar cotton varieties are undergoing field tests in India, Indonesia, and Thailand. Genetically modified maize resistant to insect pests is being tested in the Philippines.

- (iv) **Increasing Disease Resistance in Crops.** Biotechnology applied to disease resistance in crops would be especially valuable for combating diseases in tropical environments that have not been controlled by conventional means. These include important diseases such as downy mildew of maize; bacterial blight and blast of rice, papaya ringspot virus; banana bunchy top virus; and bacterial wilt of tomato, eggplant, and potato.
- (v) **Increasing Nutritional Quality.** Enhancing the protein, vitamin, and micronutrient contents of food grains would greatly benefit poor consumers who cannot afford supplementary vitamins and micronutrients. Under the Golden Rice Project, IRRI scientists are undertaking biotechnology research to

enhance the vitamin A content of rice by introducing genes from daffodil (IRRI 2001).

- (vi) **Increasing Sustainable Production of Livestock.** Research to increase the productivity and quality of farm animals, especially of dairy cows, small ruminants (sheep and goats), and water buffalo is promising. Vaccines and disease diagnostics for control of epidemic and endemic diseases of livestock are being developed.
- (vii) **Increasing Productivity in Fisheries and Aquaculture.** Development of vaccines and disease diagnostics for control of epidemic and endemic diseases of shrimp in Thailand is a good example of where modern biotechnology has been used successfully (Box 3).

Box 5.3: The Success Story of Shrimp Biotechnology in Thailand

Shrimp is one of the top 10 exports for Thailand, generating about \$1.5 billion in annual export earnings. In 1999, there were about 25,000 shrimp farms, producing 240,000 t valued at 87 billion baht (\$1.8 billion), and employing about 130,000 people.

Diseases are a major constraint in the production of cultivated shrimp. In 1994, the white spot syndrome virus became a major disease in the PRC, and quickly spread to the rest of Asia, including Thailand. The disease caused a sharp drop in shrimp production in the PRC from 155,000 t to 35,000 t, a decline of about 77 percent. National Center for Genetic Engineering and Biotechnology (BIOTEC) quickly supported research at the Universities of Chulalongkorn and Mahidol to develop DNA probe technology for the rapid detection of major shrimp pathogens. Rapid diagnostic reagents were quickly developed, the technology was transferred to the shrimp industry, and the virus was effectively controlled. It is estimated that shrimp biotechnology research and development has yielded a net benefit of about \$1 billion since 1996. That constitutes a return on investment of 5,000 times in a single year, since the total cost of the biotechnology was only \$200,000.

Source: Morakot Tanticharoen (2000).

E. Benefits from Agricultural Biotechnology

Realized or potential benefits of agricultural biotechnology can be categorized as economic, social, and environmental. A large share of the benefits are concentrated in industrialized countries, where a diversity of applications are widespread in human and animal health care and in many aspects of food production and processing. Some of the potential benefits of biotechnology are shown in Table 5.2.

As the first transgenic biotechnology product was not commercialized until 1996, little quantitative analysis has been publicly available until recently. The studies published by ISAAA (James 1997, 1998, and 2000) have helped fill the gap, at least with respect to transgenic crops. ISAAA analyzed the global status of transgenic crops, including the area planted and the value of the market for transgenic seed, which was estimated between \$2.7 billion and \$3.0 billion in 1999. The studies show that the economic benefits were fairly evenly distributed between the companies that developed the technology and the farmers growing transgenic crops.

ISAAA studies have also demonstrated positive environmental impacts. In the cases of herbicide-tolerant soybean and herbicide-tolerant canola, herbicide use was considerably reduced even though weeds were better controlled, and yields increased significantly. In the cases of Bt maize, cotton, and potatoes, targeted insect pests were effectively controlled and yields were increased. Insecticide use for nontargeted insects was also reduced.

1. Economic Benefits in Developing Countries

Few published analytical studies have attempted to assess the impact of biotechnology in developing countries. Ex-ante studies (Qaim 1999) on transgenic pest- or virus-resistant sweetpotato in Kenya and on transgenic virus-resistant potato in Mexico suggest substantial benefits for both producers and consumers. They point out, however, that smallholders will fully realize benefits only with improved farm-level management and more efficient seed distribution.

The introduction of pathogen-free banana planting material in Kenya illustrates the benefits that accrue to small-scale farmers, mainly women. Yield increases from the new material have been substantial; in some cases yields almost doubled. This example is significant in that it involved community groups and farmers in the development and field-testing. By

Table 5.2: Potential Benefits from Plant Genetic Engineering

Benefit	Example
Increasing crop productivity	<ul style="list-style-type: none"> Improving growth rate Altering ratio of usable product (e.g., increased proportion of seed in rice plants)
Increasing crop quality	<ul style="list-style-type: none"> Improving nutritional quality (e.g., specific vitamin contents, type and content of fiber, fat components, amino acids) Removing food contaminants and toxins (e.g., aflatoxins) Improving storage properties (e.g., fresh vegetables and fruits)
Environmental adaptation	<ul style="list-style-type: none"> Making crops plants better adapted to changing environments
Broadening stress tolerance	<ul style="list-style-type: none"> Making plants more resistant to drought, flooding, salinity, heavy metals, pollution
Increasing disease and pest resistance	<ul style="list-style-type: none"> Selecting resistant varieties (e.g., using molecular techniques to insert antiviral or antibacterial genes from other species) Hybridizing crops with wild relatives (e.g., use of cellular methods for rapid screening for desired phenotypes)
Agrochemical reduction	<ul style="list-style-type: none"> Breeding crop varieties resistant to specific herbicides (e.g., glyphosate-resistant soybean, through insertion of a bacterial gene that reduces sensitivity to herbicide)
Production of nonedible substances	<ul style="list-style-type: none"> Use of food crops to produce nonedible products (e.g., medicinal products and proteins, fuel alcohol, industrial oils) Using food crops for polymer and bioplastic production
Use of new raw materials	<ul style="list-style-type: none"> Production of single cell (e.g., growing bacteria on methanol for animal feed, growing mycoprotein from fungi and wastes from pulp and paper industry)

Source: Macer (1997).

the time the new planting material was available commercially, the benefits of the technology had already been demonstrated to farmers, with the result that initially demand exceeded supply. The project won the science and technology prize in a Japan/World Bank-sponsored network of environmentally beneficial development projects. The Kenyan experience is highly relevant to Asia.

2. Benefits in Asia

A number of biotechnology applications are widespread in Asia. These include biofertilizers and biopesticides, and products from tissue culture and micropropagation (banana, coconut, maize, potato, cassava). They also include diagnostics, vaccines, and embryo transfer for livestock.

An ex-post evaluation on the impact of a transgenic crop at the farm level in Asia analyzed the impact of Bt cotton in the PRC (Pray et al. 2000). A sample of 283 cotton farmers from five counties of Hebei and Shandong provinces was studied. The key findings were (i) the cost to produce 1 kg of cotton was reduced by 20–30 percent, depending on the variety and site, and (ii) net income and returns to labor of all the Bt varieties were superior to the non-Bt varieties. Smaller farms and those farms that had lower incomes consistently derived larger increases in net income than larger farms and those with higher incomes.

The use of Bt cotton substantially reduced farmers' use of pesticides, usually from 12 sprays per season to 3 or 4. The study also found some preliminary evidence of positive impact on farmers' health.

An ex-ante study on the impact of the introduction of biotechnology for the reduction of corn-borer infestation in the Philippines (Gonzales 1999) has postulated three kinds of benefits. First, the introduction of transgenic Bt maize would enhance the competitiveness of the Philippines from the point of view of import substitution and export prospects. Second, it would increase farmers' incomes. Third, it would reduce pesticide use.

F. Weighing Risks and Benefits of Biotechnology

The evidence thus far available suggests potential economic, social, and environmental benefits from the use of biotechnology. It also

suggests benefits for both food and export crops, for commercial and small farmers, and for consumers in the form of nutrition-enhanced products. The potential benefits will be realized only if a number of conditions are met:

- (i) Public institutions will need to play a key role in directing the research agenda toward social and equity goals.
- (ii) Complementarity between the public and private sectors, in both R&D and in technology development and delivery, needs to be maximized so that public investment and research is focused on those areas not of interest to the private sector.
- (iii) Governments must be committed to developing technologies for the public good to ensure that the poor, including women, have access to the new technology.

The benefits and risks of biotechnology need to be assessed on a case-by-case basis. The uncertainties and the risks are yet to be fully understood, and the benefits are not yet fully exploited. It seems important not to deny people access to new biotechnology, so long as they are fully informed of the potential risks and benefits in making their choices. We have an ethical imperative not only to keep the technology portfolio open to biotechnology and genetic engineering, but also not to lose time. Every minute lost, every decision delayed, means more deaths from starvation and malnutrition (Leisinger 2000).

VI ISSUES AND OPTIONS

A. Policy and Priority Setting

1. Issues

A surprising amount of biotechnology R&D is already being done in Asian developing countries. There have been few studies, however, on the cost-effectiveness of biotechnology R&D in these national programs, and whether priorities are research-driven or demand-driven. On the other hand, countries have a justifiable concern that they will be left behind if not involved in the technology. In establishing policies and priorities, Asian countries should consider that (i) biotechnology requires a high level of capital and specialized technical skills, (ii) the public sector is constrained by inadequate capacity, (iii) the private sector has little interest in investing in technology for poor farmers, (iv) there are potential risks associated with GMO development, and (v) it is difficult to establish an effective biosafety framework.

Some of the broad policy issues relate to capture of benefits. How can the benefits of biotechnology reach poor farmers? That is, how can biotechnology programs be better linked to extension programs? Who will be winners and losers from genetically engineered crops? Will there be a widening income gap between poor farmers and rich farmers who have access to credit to purchase biotechnology-derived seeds?

2. Options

There is a need to assist DMCs in policy and priority setting. Policy setting must be based on informed decisions on appropriate choices regarding the use of new biotechnology applications in agriculture and their prospects for enabling sustainable productivity. The likely impact of biotechnology on poor people, either directly by increasing crop yields and farm incomes or indirectly by improving their environment, should be considered.

There is a need to encourage regional and national coordination of policy on biotechnology (especially of GMOs), and consistent distribution of responsibilities between agencies in different countries. That may be difficult to achieve, but the problems of poor coordination have been

highlighted by the European experience (Levidow et al. 1999). If Asian countries are to participate more fully in biotechnology, they will also need to expand their own capacities to undertake biotechnology research linked to the problems of smallholders and marginal farmers.

B. Priorities for Research and Development

1. Issues

Countries have a range of options in determining policies and priorities for investment in biotechnology research. These might range from active promotion of biotechnology approaches, to a wait and see, stance, or to rejection of biotechnology R&D altogether. Whatever the case, technical and policy capacity will still be needed to support international trade and biosafety agreements. Donors, too, have a range of options. Should they focus their biotechnology investment on the more advanced developing countries, where there is more capacity and more likelihood of using the results? In any event, countries need to establish planning for investments based on demand. For example, is excessive emphasis given to plant biotechnology at the expense of animal biotechnology—especially given that the livestock sector is much faster growing? There is a need to establish where biotechnology methods could deliver varieties that conventional breeding cannot. Where either a conventional or biotechnology-based breeding approach could be used to target a particular characteristic, there is the need for comparative economic and risk analyses of the alternative approaches. That should also take into account that many genetic engineering approaches also require conventional crossing and selection to transfer the desired character from the transformed plant into an adapted, elite variety. Many early biotechnology research programs in Australia made the mistake of operating in isolation from breeding and agronomic improvement programs, hindering application of the research. It is important that developing countries do not repeat the mistake.

2. Options

Obtaining a clear view of which crops and characters should be targets for genetic manipulation in Asian developing countries is a critical

step, but it has rarely been addressed systematically (Woodend 1994). Research should focus on crops relevant to small farmers and poor consumers in developing countries: cassava, yam, sweetpotato, rice, maize, wheat, millet, and possibly papaya. The limitation is that relatively little biotechnology research is being undertaken on many of Asia's basic food crops or on the problems of small farmers in rainfed and marginal lands. In many cases, Asian countries will need to expand their own national and regional capacity to undertake biotechnology research to address these problems. Once a clear view is obtained on which crops and characters to target, it may make more scientific and economic sense to purchase, license, or import particular elements of technology.

Indeed, there have been a number of successes of crop genetic engineering in developing countries with technology already commercialized or in field trials. These include: insect resistance in maize and cotton and several horticultural crops using genes from Bt and other sources; resistance to a range of viruses in potato (viruses x, y, and leafroll); and ringspot virus resistance in papaya and cucurbits. Rice with resistance to bacterial blight and with increased content of beta-carotene or iron has been produced, as well as tomatoes with elevated lycopene (related to vitamin A).

Support of agricultural biotechnology research is important to developing countries for several reasons. Apart from direct benefits from applications, developing country ownership of IP can be traded for other technology. The existence of active programs in-country can provide a balanced understanding of issues by technocrats who make policy in areas such as biosafety. Some other R&D needs include the following:

- (i) One of the most profitable applications of crop biotechnology in the short term to medium term will be through better implementation of molecular markers for selection in conventional breeding programs. That will require closer linkages between biotechnologists and plant breeders in many institutes.
- (ii) Engineering of desirable traits in several of the major cereal crops of Asia (e.g., rice, maize, wheat) is being addressed by some of the international networks and through programs at IARCs. Developing country NARSs need to strengthen their ability to adopt the technologies and the germplasm as they are developed by these international initiatives.

- (iii) It will be important to identify specific orphan crops and animals with short- to medium-term potential for application of existing biotechnology in developing countries. In some cases, this may best be done through developing more efficient methods of crop improvement or through the use of MAS for complex traits. In others, the most appropriate approach may be through the development of transgenic varieties with specific characteristics such as disease resistance or improved nutritional quality.
- (iv) There is a need to ensure that the genomic knowledge of the major food crops in Asia is obtained and is available in the public domain as the basis for the development of new crop varieties for the public good. Such knowledge will underpin the development of the new food crop varieties for Asian agriculture over the next decades. The rice genomics program would be a good model for others (Sasaki 1999).
- (v) Apomixis in a wider range of crops has huge potential for simplifying the breeding of adapted genotypes, preservation of hybrid vigor, and improved propagation of crops that currently rely on vegetative propagation. It is also an important tool for the discovery of genes that are potentially important in stress tolerance.
- (vi) There is a need to build the capacity of Asian developing countries to undertake laboratory and on-site testing of GMOs. An increasing number of published protocols are available as well as simple, commercial test kits.

C. Intellectual Property Management

1. Issues

Because the private sector invests heavily in, and holds many of the advanced biotechnologies, new discoveries in biotechnology may be protected by plant variety protection, patents, or trade secrets. This raises the issue of IPR. The 1995 Agreement on Trade-Related Aspects of Intellectual Property (TRIP) requires all countries to provide some sort of protection for plant varieties. TRIP requires all signatories to extend IP protection to microorganisms, plant genetic material, and techniques used for genetic

manipulation. Although plants and animals, other than microorganisms, may be excluded from patent protection, countries are required to provide protection either by patents or by an effective *sui generis* system (see details in Appendix 13). Strengthened IPRs will increase the flow of technologies and products from developed to developing countries, and provide new incentives for local research and innovation. But one fear is that industrial nations, using genetic resources originating from developing nations, could develop GMOs or techniques and then restrict developing nations' access to the technology by employing the IPR provision of TRIP. Asian countries need to (i) develop a policy toward IP to protect their own discoveries, (ii) develop an effective approach to cooperation with the private sector in R&D, and (iii) encourage private sector research on products to benefit small farmers in Asia.

IP protection for plant genetic resources are being considered in the context of the Convention on Biological Diversity and renegotiation of the International Undertaking on Plant Genetic Resources of FAO. The issue has also been discussed in the World Intellectual Property Office in the context of traditional resource rights. In addition, environmental aspects of access to genetic resources are being discussed in UNEP and World Trade Organization (WTO). All these discussions are intended to ensure that existing international agreements encourage biotechnology development relevant to Asia's poor while protecting IPR of indigenous peoples.

Most Asian countries are members of the World Intellectual Property Office, have a national patent regime, and are signatories to the Patent Cooperation Treaty and to the Paris Convention. With the exception of the PRC, whose application is pending, most are also members of WTO.

In conformity with TRIP, a number of countries are developing plant variety protection laws and are in the process of joining the International Convention for the Protection of Plant Varieties. These include India, Indonesia, Malaysia, Philippines and Viet Nam. Some countries (Bangladesh, India, Philippines) are currently formulating laws for the protection of biodiversity and community knowledge.

Proprietary interests in biotechnology affect developing countries in several ways, requiring them to consider issues relating to the (i) *licensing in* of technology owned by developed countries or multinational companies, (ii) their *freedom to operate* with their own inventions, and (iii) their ability to commercialize or export products (Maredia et al. 1999). Changes in the last couple of decades in the IP environment in which agriculture

operates include the patenting of living organisms in some countries, and establishment of plant variety rights. The protection of target genes and of enabling technologies (e.g., gene regulation, markers for selection, promoter sequences, and transformation technologies) mean that developing country organizations have to be conversant with licensing activities. Among them are technology use agreements, material transfer agreements, and commercial licenses (Mascarenhas 1998). Some alternative strategies to gain freedom to operate can include: (i) inventing around current patents, (ii) redesigning constructs to synthesize genes to reduce reliance on external technical property, (iii) asking IP owners to relinquish claims or provide royalty-free licenses, (iv) ignoring all IP and technical property; or (v) seeking licenses for all IP and commercial property, which is certainly the safest route to building public-private sector cooperation.

Many developing countries, however, use such *inputs* without formal permission. This issue becomes important at the time of commercialization of a technique or process, or release of a variety. By then, it is often too late to change direction or incorporate an alternative piece of technology in a research or breeding program. A recent ISNAR survey of five Latin American countries showed that NARS laboratories used proprietary technologies widely, but in many cases without formal agreements. Most of the proprietary technologies related to plant genetic engineering. They included markers for selection, transformation systems, promoters, and specific genes as well as marker techniques and diagnostics. There was also a lack of knowledge regarding IPRs in both academic and administrative ranks (Salazar et al. 2000).

IP management of biotechnology inventions can be very complex. Kryder et al. (2000) recently reviewed the example of Golden Rice, which is high in pro-vitamin A (beta-carotene). This rice is potentially valuable for those who are too poor to obtain green vegetables. A very large number of proprietary technologies were used to develop Golden Rice. It is a multitransformant, since three genes were introduced into a carotenoid biosynthetic pathway to produce the high beta-carotene levels. Other proprietary technologies included three transformation vectors: *Agrobacterium* transformation, plant regeneration, and DNA amplification. Thus, a country or organization that requires this technology must obtain consent from a wide range of partners.

2. Options

The IPR issue is complex and yet many Asian institutes have focused training only on the technical aspects of biotechnology research, rather than on other areas such as licensing and IP management. Steps required to obtain consent from a wide range of partners for a given technology need to be defined on a case-by-case basis. Therefore, training in IP regulation to facilitate technology transfer in evolving IPR systems, and assistance in developing a clear understanding of TRIP agreements is important. Systems are needed to enable countries to protect their own technology, while minimizing barriers that could hinder technology transfer between countries

The adoption of IPR law by developing countries may make proprietary biotechnologies (seeds and planting materials) more costly. To overcome this problem, the public sector would need to consider buying exclusive rights to newly developed technology and make it available free to small farmers. Alternatively, the public sector and IARCs could invest in biotechnology R&D so that the resulting technology could be made available free to farmers.

D. Public-Private Sector Partnership

1. Issues

Significant increase in biotechnology investment by governments and donor agencies is crucial for achieving food security and poverty reduction. As mentioned earlier, there is insufficient profit motive to induce the private sector to undertake the R&D needed by small farmers. As Byerlee and Fischer (2000) point out, there have been significant market failures in applying biotechnology for the benefit of developing country farmers; therefore the public sector will continue to have an essential role. Because many of the techniques and products of modern biotechnology are privately owned, public agencies need modes of action to operate in an increasingly private sector world. Furthermore, both the public and private sectors have complementary assets needed for biotechnology to be applied to its full potential. Many of the results of biotechnology research will be most easily transferred to poor farmers as seeds in much the same way as the results of the Green Revolution. But

this time it is expected that the private sector will have a significant role in dissemination. The private sector, especially seed companies, is becoming more important in several Asian developing countries such as India and the PRC. Similarly, in Europe and North America several seed companies have formed alliances with global life science companies. Several Asian agrochemical and floriculture companies are involved in joint ventures with developed country companies. Thus, in line with ADB's Private Sector Development Strategy (ADB 2000), there is a need to increase the partnership between the public and private sectors.

2. Options

Present involvement of companies in agricultural biotechnology in developing countries in Asia (especially in major crops and large countries) suggests that the motivation is purely commercial. For example, seed for up to half the engineered cotton grown in the PRC has been commercially obtained from Monsanto. In many cases new mechanisms will be needed by which the private sector can assist with technology transfer, extension, and distribution of biotechnology products. That may require some innovative arrangements involving special funds and other financial incentives for private companies. Multinationals also have an incentive to involve themselves in developing country partnerships/philanthropy to counter negative public impressions. Segmentation of markets will be important to allow developing country farmers to access the products of biotechnology under realistic conditions. Brokering groups such as ISAAA, a USAID program, and CGIAR centers have already implemented a range of approaches. These include market segmentation based on crop and growth region, country income level, trade status, or crop variety. In other cases the public sector could offer to buy exclusive rights to newly developed technology and make it available either free or for a nominal charge to small farmers (but on a profit basis to commercial farmers). The private research agency would bear the risks, as it does when developing technology for the market (see details in Appendix 13). The other possibility is for the public sector agency to finance private R&D on orphan crops through competitive bidding.

There is a need to establish whether international organizations and funding agencies should play a brokering role in the dissemination of agricultural biotechnology. A neutral broker can have advantages. For

example, ISAAA claims that its comparative advantages are cosponsorship by public and private sector institutions, independence, and neutrality (lack of financial interest in the technology). Funding agencies (e.g., USAID) have also served as brokers between public agencies and private companies. Centralization of technology transfer offices for agricultural biotechnology in individual countries would facilitate brokering agreements, and inspire greater confidence in the private sector.

Other biotechnologies such as micropropagation of plants through tissue culture, and production of biofertilizers, biopesticides, and selected vaccines may be suitable for small- and medium-sized private companies in developing countries. Such companies could take technology directly from local research institutes. There are many successful examples of this already. Such enterprises can create employment in rural areas and deliver affordable and useful products to farmers.

E. Biosafety

1. Issues

Biosafety concerns relate either to food safety and human health or to the environmental impact of genetically modified crops. There is also a broader ethical concern as to whether genetically modified foods are unnatural, and whether the use of the technology encourages the narrow control of agriculture by a few (multinational) corporations. One of the key principles in biosafety guidelines is that of *substantial equivalence* as the approach to identify differences between biotechnology-derived and traditional foods (Miller 1999). The main environmental risks relate to the (i) potential loss of genetic diversity in cropping systems; (ii) potential transfer of genes from herbicide-resistant crops to wild relatives, creating superweeds; (iii) ability of herbicide-resistant crops to act as weeds in rotation crops; (iv) escape of transgenes, especially antibiotic resistance markers to soil bacteria; (v) vector recombination to create new viruses; and (vi) with Bt toxins, insect resistance to the toxin and the effect of the toxin on nontarget organisms.

The need for developing countries to have functioning biosafety systems has strengthened since the adoption of the Cartagena Protocol on Biosafety in January 2000. The Protocol establishes a framework for regulating international trade in transgenic crops. Three major components

of the Protocol have implications for individual countries as users, developers, and exporters of GMOs:

- (i) International shipments that “may contain” transgenic food products must be so labeled. This applies only to large-scale shipments; it does not affect labeling requirements on consumer products, which are determined by each country.
- (ii) Governments may use the *precautionary principle* to bar import of a transgenic product even in the absence of conclusive evidence that the product is not safe. The Protocol does not, however, override other international agreements, including WTO, which requires that import decisions be science-based.
- (iii) To assist countries in making import decisions, a database will be established to make available uniform information on transgenic crop varieties.

The need for harmonization of regulations is not just an issue for developing economies in Asia, but also for developed countries. For example, Levidow et al. (1999) report on how difficult it has been for European countries to harmonize regulatory criteria despite an expressed position of using science-based criteria. Countries disagree on the amount of scientific evidence required to resolve uncertainties such as in the recent approval processes for Bt insect-resistant maize and herbicide-tolerant canola.

2. Options

Countries have a range of options in designing and implementing national biosafety systems geared to their technical, legal, and institutional realities and in adapting the system to local needs, priorities, and capacities. There is a need to assess the adequacy and effectiveness of biosafety procedures for the testing, release, import, production, and use of GMOs in Asian countries.

Regulatory systems must be flexible to allow for either increased scrutiny or relaxation of controls (e.g., for containment of field trials) based on available scientific evidence. Harmonization of regulations between agencies is important. But it may be simpler and less expensive to embed biosafety regulation within existing institutions rather than to

build new ones. Australia's approach has been to develop national policies and regulations for trade in GMOs within the country's existing regulatory framework. Thus, governments could be helped to build the infrastructure to manage GMOs within the context of developing a quarantine policy, managing sanitary and phytosanitary issues, and assessing risk and environmental impact. Collaboration between quarantine/regulatory officials and environmental policymakers should be strengthened.

An area of potential concern is the lack of verified ecological data on the effects of genetically modified crops under Asian or tropical conditions. Governments and international agencies should be supported in participatory field studies on the ecological impact of first-generation of genetically modified crops such as insect-resistant cotton and rice. These assessments should involve local communities in the evaluation of the new technologies.

The likelihood that Asian developing countries and their agricultural export customers will adopt the labeling of food containing genetically modified products needs to be assessed. Several countries have introduced labeling systems or are considering them. In some cases, industry has expressed concerns about the extra costs involved in testing, ingredient tracing, and labeling. Several options for labeling have been proposed. They include (i) labeling based on the presence of detectable transgenic DNA or protein only; (ii) special labeling for GMO-free foods; (iii) labeling all foods derived from GMOs; and (iv) labeling foods or any food ingredients produced with GMOs (e.g., meat from animals fed with transgenic crop residues). It will be important to establish the impact of such labeling on the production, distribution, marketing, and exports of genetically modified foodstuffs.

F. Fostering Better Public Awareness

1. Issues

The future of biotechnology lies in public awareness and acceptance; good technology alone is not enough. For example, although nuclear power provided low-cost electricity for many countries, there has been substantial disadoption in recent years. The news media in several Asian developing countries regularly report on biotechnology and the controversy surrounding GMOs. Some aspects of the debate are similar to

that in Australia, in which the controversy is seen as one of technocrats encouraging the use of biotechnology versus the average person who is unsure of the benefits. European countries, especially, are seen to have the luxury of excess food production. The need to alleviate poverty or enhance food security is not part of their debate. Certain additional issues appear in some developing countries. Some countries such as Thailand are major exporters of processed foods. They are concerned about the attitudes of their export customers toward genetically modified foods.

2. Options

Inclusion of public awareness activities from the onset of a biotechnology program, rather than at its completion, can greatly assist in gaining acceptance. For example, before starting development of a transgenic, insect-resistant, tropical maize in Kenya, CIMMYT consulted with NGOs, farmer organizations, media, and other stakeholders to create a supportive environment. Public awareness programs should be included in the activities of major institutions carrying out biotechnology R&D. That is already done in Thailand and the Philippines, using simple messages in local languages. Again, it will be equally important to involve community groups in the debate, not just scientists or the food industry. Finally, multinational organizations such as Monsanto have recently realized the necessity for developing a strategy to ensure informed public debate about the risks of biotechnology to human health and the environment, and to ensure consumers are fully aware of the true benefits and costs of biotechnology. Such campaigns must recognize that freedom of choice is valid.

VII CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

During the next 25 years, Asia will face a serious challenge on how to reduce poverty and achieve food security due to (i) an absolute increase in population; (ii) the doubling of its urban population; (iii) continued deterioration of water, forest, and soil resources; and (iv) the need to produce the food where it is consumed, because the share of total grain production traded has remained stable at about 10 percent.

The most attractive strategy to meet this challenge is to increase smallholder agricultural productivity. This strategy will not only increase food supplies, but it will also increase smallholders' incomes, reduce malnutrition, and improve the livelihoods of the poor. Increasing smallholder productivity on a sustainable basis is complex. The challenge has to be addressed by modern science since the Green Revolution has already run its course in much of Asia. And it has also bypassed the rainfed and marginal area where most of the poor are concentrated.

Modern biotechnology brings new possibilities for achieving the sustainable increases in agricultural productivity that will be necessary to meet the projected demands for food by Asia's growing population. It has the potential to increase agricultural production and improve processing. Past large-scale investments in biotechnology have resulted in modest increases in crop yields, reduced dependence on pesticides, and better quality food. That could be followed by larger, dramatic increases in crop and livestock productivity; control of major diseases in livestock and fisheries; increased resistance of crops to drought, salinity, and acidity; and new types of processed foods. Using modern biotechnology, new HYVs can now be developed much more quickly with greater precision compared with conventional breeding methods.

During the past decade there has been rapid progress in the application of modern biotechnology in developed countries, thanks to massive investment of the private sector. During 1996-2000, the total area planted to genetically modified crops expanded rapidly from 1.7 million ha to 44.2 million ha. Seventy-five percent were in the United States, with the remainder in other countries in Europe, Latin America, and Asia (mainly the PRC).

Some Asian countries, notably PRC, India, Indonesia, Malaysia, Pakistan, Philippines, Thailand, and Viet Nam, have already made modest investments in agricultural biotechnology. Their capacity to carry out biotechnology R&D has been strengthened with financial support from ADB, AusAID, USAID, the Rockefeller Foundation, the World Bank, and other funding agencies. The PRC has developed and released to farmers a number of transgenic crops, which now cover at least 500,000 ha. Some IARCs have also made modest investments in biotechnology to develop HYVs of orphan crops (e.g., tropical rice, tropical maize, sorghum, groundnut, and chickpea) in collaboration with NARSS. The development of safe and efficient biotechnology in Asia has been constrained by a shortage of trained personnel, lack of capital, poor management of IPR, ineffective biosafety regulations and enforcement, and the widespread perception of some NGOs that biotechnology poses serious risks to human health and the environment.

The risks of biotechnology to human health and the environment are confined to transgenic crops and livestock or GMOs. Other components of biotechnology such as microbial fermentation, tissue culture, marker-selected breeding, and disease control are relatively safe and have no adverse impact on human health and the environment. Biotechnology consists of a gradient of technologies ranging from simple, low risk technologies to complex, expensive, and highly risky technologies. Asian governments therefore have a choice of technologies to invest in depending on the availability of human and financial resources, and their capacity to monitor and evaluate potential risks.

Agricultural biotechnology is not the sole means for achieving food security. But in conjunction with complementary activities, it may be a powerful tool in the fight against poverty. These complementary activities would include a favorable policy environment; good governance; investments in rural infrastructure, agricultural research, extension, and agricultural credit; and marketing.

B. Recommendations

1. General Strategy

To ensure that agricultural biotechnology will contribute to reducing poverty and improving food security in Asia, biotechnology R&D should do the following:

- (i) Address the problems of small farmers in the rainfed and marginal areas where most of the poor live, yet not neglect the problems of small farmers in the irrigated areas.
- (ii) Focus on economically important orphan crops, high value crops, and livestock to increase their productivity.
- (iii) Develop low cost, appropriate technologies for small farmers, particularly the development of HYVs adapted to the rainfed and marginal areas.
- (iv) Develop, test, and release technologies that will pose minimal or no risks to human health and the environment.
- (v) Strengthen the extension, delivery, and regulatory systems to ensure that improved varieties and technologies will be disseminated widely to small farmers with little or no risk to consumers or the farmers themselves.

2. Role of Government

To use agricultural biotechnology safely and effectively for the benefit of small farmers in Asia, governments in the region should:

- (i) Demonstrate a strong commitment to agriculture and rural development by providing adequate budget and staffing to the sector in general and agricultural biotechnology in particular.
- (ii) Establish clear policies and priorities in biotechnology R&D to ensure that it can contribute effectively and safely toward poverty reduction and food security.
- (iii) Enhance cooperation with the private sector in the development of biotechnology that will benefit small farmers.
- (iv) Set up effective biosafety regulatory and enforcement systems to ensure that the risks of biotechnology (particularly those of genetically modified crops and livestock) will be minimized.
- (v) Enact IPR laws that will protect and stimulate private sector investments in biotechnology in the region.
- (vi) Organize dialogue with NGOs, consumers, and farmers on the benefits, risks, and opportunities in the use of new biotechnology.

- (vii) Seek assistance from international organizations and funding agencies on specific problems in biotechnology that cannot be addressed using their own resources.

3. Suggested Policy for ADB on Agricultural Biotechnology

The major conclusion of this study is that funding agencies, including ADB, would be wise to continue and increase their investments in the safe applications of biotechnology, as one means to achieving poverty reduction and food security in Asia over the next 25 years. Achieving these goals with presently available technologies will be difficult given present trends and future challenges facing the rural sector in Asian environments. ADB can support biotechnology R&D in Asia through loans and technical assistance to both public and private sector entities. Accordingly, it is recommended that ADB consider the following measures:

Recommendation 1. ADB should assist DMCs in policy and priority setting to enhance investments in the safe application of biotechnology.

- (i) Provide information to enable governments to make informed decisions in relation to the use of new biotechnology applications in agriculture. Particular care needs to be taken to select those interventions that impact poor people, either directly by increasing incomes or crop yields and quality, or indirectly by improving their environment and prospects for sustainable productivity.
- (ii) Assist DMCs in identifying R&D areas where the use of new scientific developments may help achieve breakthroughs in dealing with previously intractable problems. These may include ways to increase sustainable productivity in rainfed areas, for example by the use of molecular methods to select new crop varieties with higher water use efficiency.

Recommendation 2. ADB should increase dialogue with its DMCs in identifying potential benefits and opportunities in the use of different biotechnologies to address specific targets.

- (i) Increase policy dialogue with governments on the importance of the rural sector in underpinning social, economic,

and environmentally sustainable development. The important role scientific developments can play in making the rural sector more productive and more sustainable through better management of natural resources is an important issue. Good governance and beneficiary participation will ensure the poor, including women, have access to the new technology.

- (ii) Support risk/benefit analyses as a basis for choices on the merits of new technologies to address particular problems relative to existing technologies and other options. An example of where risk/benefit analyses could be undertaken in the short term is on the potential use of transgenic cotton varieties in Asian cotton-growing countries, based on the experience of the use of transgenic cotton varieties in the PRC. The analyses could compare various technology options, including the use of pesticides and integrated pest management systems.

Recommendation 3. ADB should strengthen risk assessment and management capabilities in its DMCs through systematic capacity building.

- (i) Assist smaller Asian countries to set up national regulatory systems appropriate to their size and resources, while being consistent with international best practice.
- (ii) Support regional harmonization efforts and activities being undertaken through ASEAN and APEC for the development of agreed upon biotechnology standards, guidelines, and regulations.
- (iii) Support the development and implementation of protocols to monitor the long-term ecological impact of GMOs in the environment. Initial priorities could be for monitoring the performance of transgenic cotton and rice, since cotton is already under widespread commercial cultivation in the PRC and rice is the major food crop in Asia.
- (iv) Facilitate the evaluation of potential new products in the regulatory pipeline in several countries through small-scale trials conducted under international best practice guidelines. These experiments would give data that could guide risk/benefit analyses and future decisions on the safety of specific applications of new biotechnologies in Asian environments.

- (v) Strengthen law enforcement in most DMCs to ensure that the introduction and release of GMOs follow government environmental requirements and procedures.
- (vi) Support ex-ante and ex-post studies on the socioeconomic impact of transgenic crops in the region and their impact on the poor, including women.

Recommendation 4. ADB should facilitate access to proprietary technologies and encourage greater private and public sector cooperation in the development and delivery of new products at affordable prices for the poor.

- (i) Facilitate negotiations with private companies on behalf of developing countries and the international agricultural research community to access key enabling technologies potentially useful on orphan commodities in Asia (i.e. staple food crops, livestock, and fish consumed locally).
- (ii) Act as an honest broker or as a convenor in facilitating more public-private sector partnership in research, development, and dissemination of technologies relevant to the needs of small farmers.
- (iii) Examine the feasibility of providing incentives for local private sector development in areas that would develop biotechnology-based businesses in rural areas, with high potential for stimulating income and employment opportunities.
- (iv) Examine the feasibility of providing incentives for multinational companies to develop products to benefit poor people. Such incentives may be provided through tax breaks, contract R&D, guaranteeing a base market for a successful product, strategic alliances, or underwriting joint ventures with national companies. There are some experiences with these types of incentives in the health sector that merit closer examination for their applicability to the rural sector.
- (v) Support national capacity building in IP management and technology transfer.

Recommendation 5. ADB should support a strategic R&D agenda and associated human resources development in Asia to generate new knowledge and disseminate the results for the public good. It should

support and fund national governments and IARCs to undertake important initiatives that will have significant impact on poverty reduction and food security in the long term in areas of market failure where the private sector is unlikely to invest.

- (i) **Applications of Biotechnology to Orphan Commodities.** Support public R&D on orphan commodities by national and international agencies. This may best be done by developing more efficient methods of crop improvement through the use of marker-assisted selection for complex traits such as drought tolerance. In other cases, the most appropriate approach may be the development of transgenic varieties with specific characteristics such as disease resistance or improved nutritional quality.
- (ii) **Ecological Research.** Support national governments and international agencies in developing methods for undertaking participatory field studies on the ecological impact of the first generation of genetically modified crops. For example, insect-resistant cotton and rice are being released for field testing and commercial production in Asia, particularly in the PRC. These assessments should involve local communities in the evaluation of the new technologies, similar to the approaches developed in Asia for integrated pest management.
- (iii) **Strategic Research on Functional Genomics.** Support regional efforts on functional genomics to understand the genetic basis of the agriculturally important crops and livestock in Asia. For example, genomic studies on rice, maize, and sorghum may identify potentially useful genes for drought and salinity tolerance that may have wide applicability across all cereals.
- (iv) **Exchange of Information.** Support the sharing of knowledge and experience among Asian countries on the applications of biotechnology to specific targets, the risk/benefit analyses that underlie particular choices, and the data on food safety and environmental risks that will be acquired as experience accumulates and strategic R&D is conducted.

APPENDIX 1 TECHNIQUES OF BIOTECHNOLOGY

A. Evolution of Modern Genetics

Modern genetics commenced around 1900, with the rediscovery of the work of Gregor Mendel and other European scientists that showed traits were inherited. Since 1900, there has been steady progress in understanding the genetic makeup of all living organisms ranging from microbes to humans. A major step forward in human control over genetic traits useful in agriculture was taken in the 1920s when Muller and Stadler discovered that radiation can induce mutations in animals and plants. In the 1930s and 1940s, several new methods of chromosome and gene manipulation were discovered. Later, commercial exploitation of hybrid vigor in maize and other crops began, and techniques such as tissue culture and embryo rescue were used to obtain viable hybrids from distantly related species (Serageldin and Persley 2000).

The double helix structure of deoxyribonucleic acid (DNA), the chemical substance of heredity, was discovered in 1953 by Watson and Crick. That triggered rapid progress in every field of genetics, leading to new molecular genetics applications in agriculture, medicine, and industry.

B. Recombinant DNA Technologies

In the 1970s, a series of complementary advances in molecular biology gave scientists the ability to readily move DNA between closely related and more distantly related organisms. The technique, known as recombinant DNA (rDNA) technology, has now reached the stage where a piece of DNA containing one or more specific genes can be taken from nearly any organism, including plants, animals, bacteria, or viruses, and introduced into any other organism. This process is known as transformation. The application of rDNA technology is called genetic engineering. An organism that has been improved, or transformed, using modern techniques of genetic exchange is commonly referred to as a genetically improved organism, a genetically modified organism (GMO), or a living modified organism.

The offspring of any traditional cross between two organisms also are genetically improved relative to the genotype of either of the contributing parents. Not all genetically improved organisms involve the use of cross-species genetic exchange. Recombinant DNA technology also can be used to transfer a gene between different varieties of the same species. Strains that have been genetically improved using rDNA technology are known as transgenic strains and the specific gene transferred is known as a transgene. The technique can also be used to modify the expression of one or more of a given plant's own genes, such as the ability to amplify the expression of a gene for disease resistance (Persley and Siedow 1999).

The most striking differences between the techniques of modern biotechnology and those used earlier to breed new strains of crop and livestock lie in the increased precision with which the new techniques may be used and their ability to speed breeding programs.

C. Understanding Plant and Animal Genes

The past two decades have seen dramatic advances in understanding how biological organisms function at the molecular level, as well as in the ability to analyze, understand, and manipulate DNA molecules and the genes that they form. This understanding has been accelerated by the Human Genome Project that has invested substantial public and private resources into the development of new technologies to work with human genes. The same technologies are directly applicable to all other organisms, including plants, animals, insects, and microbes. Thus, the new scientific discipline of *genomics* has arisen. Genomics has contributed to powerful new approaches to identify the functions of genes and their application in agriculture, medicine, and industry.

Genomics refers to determining the DNA sequence and identifying the location and function of all the genes contained in the genome of an organism. The advent of large-scale sequencing of entire genomes of organisms as diverse as bacteria, fungi, plants, and animals is leading to the identification of the complete complement of genes found in many different organisms. This is dramatically increasing the rate at which an understanding of the function of different genes is being achieved. This new knowledge will radically change the future of breeding for improved strains of crops, livestock, fish, and tree species.

The present major technical limitation to improving agriculture through the applications of rDNA technology is insufficient understanding of exactly which genes control agriculturally important traits and how they function. That is why new developments in understanding gene function and linking this new information to breeding and genetic resources conservation programs is so important.

Research in plant genome projects shows that many traits are *conserved* (that is, shared) within and even between species. The same gene(s) may confer the same trait in different species. Thus, a gene for salt tolerance in fish may confer that same salt tolerance if transferred to and expressed in rice. Similarly, a gene for drought tolerance in millet may also confer drought tolerance if transferred to maize. These advances in genomics should lead to a rapid increase in the identification of useful traits that will be available to enhance crop plants and livestock in the future. In animal health, knowledge of the genome of a parasite should assist in identifying essential proteins of the parasite against which an immune response can be targeted, and hence may accelerate vaccine development for livestock diseases.

The first genome sequence of an organism more complex than a virus was published in 1996. Already 23 genome sequences are available. Some 60 or more genome sequencing projects of a wide variety of organisms, including plants, animals, parasites, and microbes, are under way (Serageldin and Persley 2000). The first complete sequence of a plant genome (*Arabidopsis*) is now available, and the rice genome is close to completion. Examples of the genomic structure of different organisms are given on the web site of the Institute for Genomic Research (<http://www.tigr.org>).

D. Functional Genomics for Trait Discovery

Much of the discussion about molecular biology is focused on the opportunities and risks associated with gene transfer through transformation and the development of GMOs. When linked with marker-assisted selection, the same science gives plant and animal breeders new tools to identify and transfer genes through more conventional breeding approaches. This is of particular significance in developing country environments, since future gains in productivity will depend upon manipulation of complex traits such as drought or heat tolerance. These traits are often difficult to identify

and use in a conventional breeding program. For future crop improvement, plant genomic projects will be the engine to drive trait discovery and help solve intractable problems in crop production (Flavell 1998).

A completely sequenced plant genome such as rice, for example, will provide a large pool of genetic markers and genes for rice improvement through marker-assisted selection or genetic transformation. To fully exploit the wealth of molecular data, it is necessary to understand the specific biological functions encoded by DNA sequences through detailed genetic and phenotypic analyses. Thus, unlike genome sequencing *per se*, functional genomics requires diversity of scientific expertise as well as genetic resources for evaluation. In many important food crops, national and international public sector research has a large investment in genetic resources and breeding materials, and a long history of understanding biological function and genotype x environment interactions. These scientific and biological resources will become increasingly important in gaining knowledge about the function of genes and in developing molecular markers to assist the breeding process.

The collection and storage of so much sophisticated genetic information in computerized databases by both the private and public sectors, and the patenting of genes and enabling technologies, require a new paradigm for using new biotechnologies to improve crops and livestock, especially in the poor countries where food needs are most urgent. This paradigm requires public and private partnerships between advanced genomics specialists, breeders, and scientists knowledgeable about the species upon which the world depends for food (Flavell 1998).

APPENDIX 2 APPLICATIONS OF BIOTECHNOLOGY TO AGRICULTURE

A. Crops

The applications of modern biotechnology to crops are in the following areas:

- (i) Diagnosis of pests, diseases, contaminants, and quality traits.
- (ii) Micropropagation and tissue culture techniques.
- (iii) Genetic markers, maps, and genomic information in marker-assisted and gene-assisted selection and breeding.
- (iv) Transgenic plants with higher yields; disease and pest resistance; tolerance for environmental stress; and improved nutritional quality.

1. Diagnostics as an Aid to Crop Production and Protection

Diagnostics based on the use of antibodies and nucleic acid technologies, in comparison with simple testing formats, has improved the specificity, sensitivity, and ease of diagnosis of plant pests and pathogens, contaminants, and quality traits. These new diagnostics have also greatly assisted in the study of the ecology of pests and diseases and in their more rapid identification in quarantine. These techniques are now widely used in industrialized countries, and increasingly in emerging economies.

2. Micropropagation and Tissue Culture Techniques

Tissue culture and other micropropagation techniques are a practical means of providing disease-free plantlets of current varieties with significantly increased yields by the removal of pests and pathogens. These technologies have been especially useful in vegetatively propagated species (i.e. those that do not readily produce seed) such as sweetpotato and banana. It is relatively widely used in developed and developing countries, particularly in tropical countries. Indonesia and Thailand, for example, have replanted much of their rubber and oil palm estates using tissue-cultured material. Tissue culture is also a critical step

in the development of transgenic plants by enabling the regeneration of transformed cells containing a novel gene.

3. Modern Plant Breeding

The application of biotechnology to agricultural crops has traditionally involved the selective crossing of two parent plants to produce offspring having desired traits such as increased yields, disease resistance, or enhanced product quality. Such active plant breeding has led to the development of superior plant varieties far more rapidly than would have occurred in the wild due to random crossing.

Traditional methods of gene exchange, however, are limited to crosses between the same or closely related species. It can take considerable time to achieve desired results, and frequently, genes conveying desirable traits do not exist in any closely related species. Modern biotechnology, when applied to plant breeding, vastly increases the specificity of introduction of the desired gene or characteristic. Further it reduces the time in which changes in plant characteristics can be made by up to 50 percent. And it increases the potential sources from which desirable traits can be obtained.

Recombinant DNA Technology. The application of recombinant DNA (rDNA) technology to facilitate genetic exchange in crops by transformation complements traditional breeding in several ways. The exchange is far more precise because only a single gene that has been identified as providing a useful trait is transferred to the recipient plant. There is no inclusion of ancillary, unwanted traits that need to be eliminated in subsequent generations as often happens with traditional plant breeding. Approximately 30,000 unnecessary alleles can be introduced by conventional crossing programs.

The technical ability to transfer genes from any organism into another means that the entire span of genetic capabilities available among all biological organisms potentially can be transferred to any other organism. This markedly expands the range of useful traits that ultimately can be applied to the development of new crop varieties.

Marker-Assisted Selection. The use of genetic markers, maps, and genomic information is increasing the accuracy and reducing the time to commercial exploitation of single and polygenic traits in plant breeding.

For example, the use of marker-assisted selection in breeding for disease resistance in rice by the International Rice Research Institute and members of the ADB-funded Asian Rice Biotechnology Network has led to the development of lines with resistance to bacterial blight.

The present major technical limitation on the application of rDNA technology to improving plants is insufficient understanding of exactly which genes control agriculturally important traits and how they function. That constraint can be addressed through studies of plant genomes, which identify the structure and function of all genes in a species.

Genomics. The rapid progress being made in genomics should greatly assist conventional plant breeding as the functions of more genes are identified. That may enable more successful breeding for complex traits such as drought and salt tolerance, which are believed to be controlled by many genes. Breeding for such complex traits has had limited success with conventional breeding of the major staple food crops. In contrast, resistance for many common plant diseases and pests may be possible through a single gene or a small number of genes.

The initial potential of comparative genetics may best be demonstrated with traits where gene action is simple and well understood. Among these are disease- and insect resistance, submergence tolerance, starch accumulation, phosphorus uptake, tolerance for soil toxicity, and flowering response.

4. Bioinformatics

The Consultative Group on International Agricultural Research (CGIAR) centers have accumulated a huge resource of data from their germplasm collections, and crop improvement and international testing programs over the past 30 years. Research in molecular biology, genome sequencing, functional genomics, and comparative genetics are producing large amounts of new genomic data. Bioinformatics is essential for the management, integration, and analysis of phenotypic and genomic data if the promise of molecular biology for genetic improvement is to be realized.

New discoveries in comparative genetics indicate a high degree of conservation of genetic material across the genomes of many species. This applies to gene order and gene structure, and has important implications for translating findings in the molecular biology of one species to

others. Unless the bioinformatics tools are also compatible across species, that will not be possible.

Numerous research projects worldwide are collecting genomic data. These are often made available for bioinformatic analysis in public databases. The task of linking these data resources and analyzing the product is too great for any one institution to handle. People with skill and experience in this new and rapidly changing field are rare and dispersed.

5. Commercial Applications of Transgenic Crops

Commercial cultivation of the first generation of new transgenic crop varieties began in 1996. In 1999, approximately 40 million hectares worldwide were planted with transgenic varieties of over 20 crop species. The most commercially important were cotton, maize, soybean, and canola (James 2000). These new crop varieties are grown in Argentina, Australia, Canada, the Peoples Republic of China, France, Mexico, South Africa, Spain, and the United States (US). Approximately 15 percent of the area is in emerging economies. The value of the global market in transgenic crops grew from \$75 million in 1995 to \$1.64 billion in 1998.

The traits these new varieties contain are most commonly insect resistance (cotton, maize), herbicide resistance (soybean), delayed fruit ripening (tomato), and virus resistance (potato). The growth in the area of transgenic crops from 1996 to 2000 is shown in Table A2.1. The global area of transgenic crops by country is in Table A2.2. The global area of individual crops is in Table A2.3.

Table A2.1: Global Area of Transgenic Crops, 1996-2000

Year	Hectares (million ha)	Acres
1996	1.7	4.3
1997	11.0	27.5
1998	27.8	69.5
1999	39.9	98.6
2000	44.2	109.0

ha = hectare.

Source: James (1998, 2000).

Table A2.2: Global Area of Transgenic Crops by Country, 1998-2000
(million ha)

Country	1998	%	1999	%	2000	%
USA	20.5	74	28.7	72	30.3	68
Argentina	4.3	15	6.7	17	10.0	23
Canada	2.8	10	4.0	10	3.0	7
PRC	<0.1	<1	0.3	1	0.5	1
Australia	0.1	1	0.1	<1	0.2	<1
South Africa	<0.1	<1	0.1	<1	0.2	<1
Mexico	0.1	<0.1	<0.1	<1	<0.1	<1
Spain	<0.1	<1	<0.1	<1	<0.1	<1
France	<0.1	<1	<0.1	<1	<0.1	<1
Portugal	0.0	0	<0.1	<1	—	—
Romania	0.0	0	<0.1	<1	<0.1	<1
Ukraine	0.0	0	<0.1	<1	—	—
Total	27.8	100	39.9	100	44.2	100

— = not available, ha = hectare.

Source: James (1998, 2000).

Table A2.3: Global Area of Transgenic Crops, 1998-2000
(million ha)

Crop	1998	%	1999	%	2000	%
Soybean	14.5	52	21.6	54	25.8	58
Maize	(0.3)	30	11.1	28	10.3	23
Cotton	(0.5)	9	3.7	9	5.3	12
Canola	(0.4)	9	3.4	9	2.8	7
Potato	(-)	<1	<0.1	<1	<0.1	<1
Squash	0.0	0	<0.1	<1	<0.1	<1
Papaya	0.0	0	<0.1	<1	<0.1	<1
Total	27.8	100	39.9	100	44.2	100

ha = hectare.

Source: James (1998, 2000).

Other crop trait combinations being field-tested in various countries include virus-resistant melon, papaya, potato, squash, tomato, and sweet pepper; insect-resistant rice, soybean, and tomato; disease-resistant potato; and delayed ripening chili pepper. There is also work in progress to use plants such as maize, potato, and banana as biofactories for the production of vaccines and biodegradable plastics. Other research is aimed at modifying the nutritional content of crops, for example by modifying the oil content (canola), increasing the amount and quality of protein (maize), or increasing vitamin A content (rice) (James and Krattiger 1999).

B. Characterizing Biodiversity

Modern biotechnology also offers new opportunities for characterizing, conserving, and using biodiversity. Comparative studies may facilitate (i) the systematic search for useful genes that may be found in one germplasm selection without having to discover the genes for a particular trait in each crop, (ii) identification of genetic resources containing useful allelic combinations, (iii) understanding the genetics underlying important traits, and (iv) understanding the structure of diversity that will enhance management of germplasm collections.

Comparative genetics provides the potential for trait extrapolation from a species in which the genetic control is well understood, and for which there are molecular markers, to a species for which there is a limited amount of information. Rice, for example, is regarded as a model for cereal genomics because of its small genome. The similarity of cereal genomes means that the genetic and physical maps of rice can be used as reference points for the exploration of the much larger and more difficult genomes of the other major cereal crops. They can also be applied to the minor cereals. Conversely, decades of breeding work and molecular analysis of maize, wheat, and barley can now find direct application in rice improvement. These studies are much more advanced for cereals than for roots and tubers, and legumes. That reflects the large public and private sector investments in the rice genome project (coordinated by Japan), and other investments in maize and wheat in Europe and North America.

The research agenda for the different groups of crop species are similar. Opportunities to apply comparative genetics now are furthest

advanced in the cereals in which considerable research investment has already been made (e.g., rice, wheat, maize, sorghum).

Without significant investment in the short term, the research gap in comparative genetics between the national research institutes in Asia and the CGIAR centers and advanced laboratories will widen. Collaboration with advanced laboratories is essential to fully exploit the potential of comparative genetics.

C. Forestry

1. Tree Breeding and Selection Programs

Tree breeding programs and selection of superior tree types (provenances) have been responsible for remarkable increases in wood productivity. In conventional breeding, the chance of selected traits being transferred to offspring is still governed by chance. Biotechnology now enables breeders to accurately pinpoint in what part of the chromosome the selected traits can be found and to transfer the gene from the parent to the recipient. This approach is especially important in tree breeding because of the much slower growth rates of trees compared with annual crops.

Marker-assisted selection helps breeders determine the location of genes that control important traits. It is easier and cheaper to select plants that have the DNA marker than to grow the plants to maturity to see if they develop the desired trait. This approach is especially useful for trees with a long life cycle. Marker-assisted selection is being done in pine trees, eucalyptus, acacias, coconut, and dipterocarps.

2. Macropropagation by Cuttings

Vegetative propagation or macropropagation by cuttings is still the most practical approach for some trees. Large plantations of pines have been planted by cuttings in New Zealand and the US, and of eucalyptus in Africa and Brazil. Macropropagation also underlies much of the nursery development for reforestation in developing countries.

3. Micropropagation by Tissue Culture

Micropropagation has great potential in producing large quantities of genetically superior plantlets. Protocols for the tissue culture of eucalyptus, pines, and other trees are now available and are being use in the propagation of high-quality planting material.

4. DNA Fingerprinting

Living organisms that have different characteristics also have different DNA sequences. DNA fingerprinting offers an accurate way to differentiate species, strains, and cultivars. For example, it is difficult to differentiate between provenances of *Acacia mangium* mainly through phenotypic characters. But the differences between provenances and cultivars can be rapidly analyzed by DNA fingerprinting.

5. Applications of Forest Biotechnology for Food and Wood Security

Advances in biotechnology have direct implications in food and wood security. Biotechnology can provide the tools needed for the proper selection of genetically superior trees for breeding purposes; their mass propagation by macro- and micropropagation techniques; the production of high quality biofertilizers including mycorrhiza and nitrogen-fixing organisms; and the production of microbial pesticides for biological control. The long-term implication is on the use of biotechnology in the production of transgenic trees, which may contain genes tailored to produce their own insecticides or to tolerate biotic and abiotic stresses.

Work is under way in the Philippines in the selection, breeding, and mass propagation of industrial tree plantation species. Protocols for macropropagation of *Eucalyptus* species, *Gmelina arborea*, dipterocarps, acacias, and others are being studied. Likewise micropropagation techniques are being developed for these trees, as well as for other forest plants such as rattan and bamboo (de la Cruz 2000).

D. Livestock

1. Livestock Improvement

The main applications of new biotechnologies to livestock are in genetic improvement, reproductive technologies (e.g., fertility monitoring and embryo transfer), and animal health (through diagnostics and vaccines). These new technologies speed the reproductive process, thus allowing more generations to be produced over the life of an animal. They also enable the more efficient selection of breeds with increased productivity.

Phenotypes of commercial livestock breeds that are highly productive under intensive production systems in temperate climates do not realize their production potential in subtropical or tropical production systems. Dietary constraints, inability to adapt to local environments, and susceptibility to disease are among the factors responsible.

Advances have been made in overcoming the genotypic constraints to increased production efficiency. Improvements have been made both in genetic characterization at the molecular level, and in technology to rapidly expand the available numbers of improved genotypes. Linkage maps of sufficient resolution for use in breeding improvement schemes based on marker-assisted selection are now available in Australia, US, and Europe for cattle, pigs, poultry, and fish. These maps are being refined, and the process of identifying molecular markers for desirable biological and commercial traits is under way. In several cases, these approaches are already being applied in the identification of elite sires.

The application of comparative genomics between breeds and species may mean that such selection strategies for desirable traits in one species/breed may be more easily adapted to that of other species/breeds. However, the high cost of genomics presently limits the technology to lucrative markets, breeds, species, and production environments in the industrial world.

2. Transgenic Livestock

The demonstration of the technical ability to clone a mammalian species with the cloning of *Dolly* the sheep in the UK created both excitement and concern. Practical applications of the technology are presently restricted to production of human biological pharmaceuticals in the milk of sheep. There has also been work on the creation of transgenic lines of

virus-resistant poultry, which contain a modified virus gene that confers disease resistance. Small herds of transgenic animals likely will be able to produce sufficient quantities of high-value biological products, such as pharmaceuticals, in the immediate future.

3. Livestock Health

The development and application of diagnostics for the major livestock diseases has helped to identify the cause of poor performance of livestock in developing countries, and in understanding the reasons for the spread of certain diseases. Molecular technologies, involving antibodies and DNA or RNA probes, are also applicable to the study of livestock parasites and other pathogens. They provide effective means for identifying, isolating, characterizing, and producing molecules that can induce protective responses against the parasite, leading to the development of vaccines (Morrison 1999). The new technologies can also be used to generate products such as antibodies and gene sequences, which can form the basis of improved diagnostics. Genetic markers are increasingly used to identify, with greater precision, the species, subspecies, and types of pathogenic agents. Recombinant or genetically modified pathogens also offer new approaches to vaccine delivery, as does direct injection of DNA into animals.

Vaccines developed using traditional approaches have had a major impact on the control of the epidemic viral diseases of livestock such as foot-and-mouth disease. There are many other important diseases, notably parasitic diseases, for which vaccines have not been developed and for which modern biotechnology offers great promise.

Two main approaches are being pursued to develop vaccines using rDNA technology. The first involves the deletion of genes known to determine virulence of the pathogen, thus producing attenuated organisms (nonpathogens) that can be used as a live vaccine. This strategy is presently more appropriate for viral and bacterial diseases than for protozoan parasites. Such vaccines have been developed for the herpes viruses that cause a disease in pigs. The second strategy is to identify protein subunits of pathogens that can stimulate immunity. That is the preferred approach to many of the more complex pathogens such as those that cause tick-borne diseases of cattle and buffalo.

Vaccine development for domestic livestock could benefit from technology spillover from vaccine development for humans because the

same research concepts and approaches can be applied, albeit to different pathogens.

E. Fisheries and Aquaculture

Molecular markers are of growing importance in biodiversity research, genome mapping, and trait selection in fish and other aquatic organisms. International groups are already collaborating on developing genetic maps of tilapia, common carp, salmonids, catfish, zebra fish and puffer fish.

The feasibility of developing and using transgenic species of fish is being explored by several research institutes and companies in the UK and the US on various species including tilapia and salmon. Indeed, transgenic salmon is close to commercialization in the US. Transgenesis may become a cost-effective means of enhancing indigenous species important to one or a few countries, but not covered by international breeding efforts.

A wide range of new molecular diagnostic techniques is being developed for applications such as disease diagnosis (for example, the major Asian shrimp diseases of white spot and yellow head). The techniques can also be applied to the sexing of juvenile fish and for assessing progeny relationships in large populations of fish raised together to reduce environment-specific variations in production. Other techniques include tissue culture, or other manipulations of embryos or embryonic cells, for the isolation of viruses, bacteria, and fungi pathogenic to fish.

APPENDIX 3 AGRICULTURAL BIOTECHNOLOGY IN THE PEOPLE'S REPUBLIC OF CHINA⁴

A. Introduction

Global commercial production of transgenic crops has increased rapidly in the last few years (James 1998). There is considerable research and development (R&D) in agricultural biotechnology in the People's Republic of China (PRC), especially in crop improvement and production. Environmental degradation resulting from intensive cropping is another agricultural concern in the PRC.

There is also a huge demand for improved quality of food products, especially grain quality of cereals. Quality improvement of rice, for example, was largely neglected in breeding programs in recent years. High-yielding cultivars and hybrids are frequently associated with poor cooking and eating quality. Thus, they are not favored by producers or consumers.

Increasingly frequent natural disasters such as floods, drought, insect pest infestations, and diseases have been experienced in the PRC. And areas of soil desertification, salinity, and acidity are expanding. Excessive applications of chemicals has resulted in a rapid deterioration of the environment, which has made crop production even more dependent on chemicals.

The greatest challenge is to increase food production and improve product quality in an environmentally sustainable manner.

B. Developments in Biotechnology

In the last 15 years, there have been rapid developments in the PRC in scientific infrastructure and in research programs in biotechnology and molecular biology of various crop plants. Infrastructure developments include the establishment of National Key Laboratories in agricultural biotechnology and in crop genetics and breeding in north, central, and

⁴ See Zhang (2000).

south PRC. In addition, there are open laboratories supported by the Ministry of Agriculture, the Ministry of Education, and the Chinese Academy of Sciences.

In the 1990s, regular funding channels were formed at the central Government level to support basic and applied research. The National Natural Science Foundation of China (NNSFC) and the Chinese Foundation of Agricultural Scientific Research and Education were established. Major research initiatives and programs were also established at the state level and by various ministries. The most important programs for biotechnology R&D are the National Program on High Technology Development (also known as the 863 Program) and the National Program on the Development of Basic Research (also known as 973), both of which include agricultural biotechnology as a major component. Programs were set up to promote young scientists by awarding special grants from the NNSFC, the 863 Program, and various ministries. Similar smaller systems were developed by local governments in many provinces. International funding channels also opened to Chinese scientists during the period, including Rockefeller Foundation, McKnight Foundation, International Foundation for Science, and European Union-China collaboration programs. Some of the programs have a training component as well.

Rapid advances were made in molecular biology and biotechnology research in the PRC in the 1990s. These include genomic studies in rice and other cereals; development of molecular marker technologies; and identification, mapping, and molecular cloning of a large number of agriculturally useful genes. These studies have resulted in powerful tools for varietal improvement (e.g., marker-assisted selection [MAS]) that can be applied to develop new cultivars and hybrid parents.

Transformation technologies have also been established in many laboratories for most crop species including maize, rice, and wheat, which are often considered difficult to transform. Transgenic plants can now be routinely produced for rice, maize, wheat, cotton, tomato, potato, soybean, canola, and other crops using *Agrobacterium*, particle bombardment, or other methods.

The most up-to-date molecular technologies necessary for varietal development are now in place in the PRC.

C. Opportunities

Genome mapping and biotechnology research offer powerful tools in crop improvement, including genetic transformation and molecular MAS. These techniques can be applied to disease and insect resistance, tolerance for abiotic stresses, product quality, and increasing yield potential.

1. Disease Resistance

More than 20 genes for resistance to various plant diseases have been isolated in recent years (Baker et al. 1997). Analyses of the DNA sequences indicate that the genes share many structural characteristics in common, despite the fact that diseases are caused by a variety of pathogens such as fungi, bacteria, viruses, and nematodes. The genes were isolated from a wide range of plant species including monocotyledonous and dicotyledonous species including tomato, rice, tobacco, and barley. These have provided a rich source of disease-resistance genes for improving resistance by genetic engineering.

Large numbers of genes have been tagged and mapped using molecular markers in many crop species (Zhang and Yu 1999). Closely linked markers flanking both sides of the genes were identified in many cases. These closely linked markers can be used as the starting points for isolating the genes using the map-based cloning approach, or in MAS to monitor the transfer of the genes. New crop lines with increased resistance have been obtained using both approaches.

2. Insect Resistance

Genes for resistance to various insects have been identified in many crop species and their wild relatives, including gall midge and brown planthopper resistance in rice, and pink borer resistance in cotton. A number of insect resistance genes have also been genetically tagged and mapped using molecular markers (Zhang and Yu 1999). These genes can be directly used in crop breeding programs using MAS.

An important strategy in the development of insect-resistant crop varieties is the use of exogenous genes, including genes coding for endotoxin of *Bacillus thuringiensis* (Bt) and proteinase inhibitors from various sources (Krattiger 1997). Some of the genes have demonstrated strong

insecticidal activities in the laboratory and in the field. Several genes have now been widely used in transformation studies. Many insect-resistant transgenic cotton, maize, and rice plants have been produced from these transformation studies, and are now in commercial production (James 1998).

Large-scale use of resistance genes in crop production will not only reduce labor and costs of production, it will also have long-term beneficial effects on the environment. These insect-resistant crops may play a major role in sustainable agricultural systems.

3. Tolerance for Abiotic Stresses

Drought, and soil salinity and acidity are among the most important constraints to agricultural production. They cause severe yield losses of all major food crops worldwide. In the drought prone northwest, water is a major limiting factor for crop production; in south and central PRC, soil acidity is a major limiting factor; and salinity affects large areas in the east coast region.

Drought tolerance has been the subject of many studies in several major food crops including rice, maize, and sorghum (Nguyen et al. 1998). Although many quantitative trait loci (QTLs), which explain certain genetic variations in drought tolerance in experimental populations, have been identified by molecular markers, they are unlikely to play a major role in improving the drought tolerance of crops.

There have also been QTL studies on the tolerance of rice for acidic soils, especially with respect to aluminum and ferrous iron toxicity. Wu et al. (1999) showed that major gene loci may be involved. That may present an opportunity for using genes from rice itself to improve the tolerance of rice varieties for acidic soils.

A more promising line of research is the use of gene coding for citrate synthase, the enzyme for biosynthesis of citric acid (de la Fuente et al. 1997). Transgenic sugar beet plants with elevated expression of this gene show an enhanced tolerance for aluminum, and increased uptake of phosphate in acidic soil as a result of excretion of citrate. That indicates that genetic engineering may be able to produce plants that can grow better in acidic soil, even with reduced application of phosphate fertilizers. This work may have tremendous implications in crop improvement, especially for crops grown in the tropics and subtropics.

4. Grain Quality

Biotechnology may have a lot to offer in the improvement of grain quality. In rice, for example, the poor cooking and eating qualities of high-yielding cultivars and hybrids represent a major problem for rice production in the PRC. Research has established that the cooking and eating qualities are to a large extent dependent on three traits: amylose content, gelatinization temperature, and gel consistency. All three traits are controlled by the waxy locus located on chromosome 6 (Tan et al. 1999).

The waxy gene was isolated from maize and rice (Shure et al. 1983, Wang et al. 1990). Rice plants transformed with the waxy gene, both in sense and antisense configurations, showed reduced amylose content, thus demonstrating the usefulness of the transgenic approach in improving cooking and eating qualities. Moreover, the waxy locus has also been clearly defined in the molecular linkage map. Markers residing on the waxy locus and closely linked markers that flank the waxy locus on both sides were identified (Tan et al. 1999). Improvement of the cooking and eating qualities can therefore be achieved using MAS.

Another example is the recent success in engineering the entire biochemical pathway for provitamin A biosynthesis (Al-Babili et al. 1999), which significantly enriched vitamin A content in the endosperm of rice grains. That will be a great help to poor farmers to balance the micronutrients in their diets and hence alleviate malnutrition.

5. Increasing Yield Potential

Several major crop species have gone through two great leaps in yield increase in the last several decades: increasing harvest index by making use of semidwarf genes, and taking advantage of heterosis in hybrids. Yield declines have been observed in a number of major food crops in the last 10-15 years (Ministry of Agriculture 1996). Increasing yield potential has therefore been a common concern in essentially all crop-breeding programs.

Two approaches have been reported in the literature. The first approach is called *wild QTLs*, in which efforts are devoted to incorporating QTLs for yield increase from the wild relatives into cultivars. The argument for such an approach is that only some of the genes that existed in the wild species were brought into cultivated species in the processes of domestication, leaving most of the genes unused. With the help of molecular

marker technology, it should be possible to identify genes that can increase the yield of cultivated plants. Xiao et al. (1996), for example, reported two QTLs from a wild rice that showed significant effects in increasing the performance of an elite rice hybrid. That has generated considerable interest in identifying potentially useful genes from wild relatives for varietal improvement.

The second approach is to modify certain physiological processes by genetic engineering. Gan and Amasino (1995) reported a system conceived to delay leaf senescence by autoregulated production of cytokinin. The construct was designed by fusing a senescence-specific promoter isolated from *Arabidopsis* with a DNA fragment from *Agrobacterium* encoding isopentenyl transferase, an enzyme that catalyzes the rate-limiting step in cytokinin biosynthesis. The strategy for such a system is that (i) the gene would be turned on at the onset of senescence leading to (ii) the synthesis of cytokinin, and (iii) the production of cytokinin would in turn inhibit the process of senescence, thus (iv) repressing the expression of this construct itself. Such a system would, therefore, produce cytokinin for delaying senescence, and at the same time prevent overproduction of cytokinin, which is detrimental to the plant. Transgenic tobacco plants carrying this construct showed a significant delay in leaf senescence, bringing about a large increase in the number of flowers, number of seeds, and biomass. It would be interesting to determine if this system could provide a general strategy for yield increase in crop improvement.

D. Field Testing of Transgenic Crops

Transgenic research has been conducted on 47 plant species in the PRC using 103 genes. A national committee for the regulation of biosafety of genetically improved agricultural organisms was established in 1996 to promote biotechnology in a healthy environment. This committee accepts applications twice a year for biosafety evaluation of genetically improved agricultural organisms such as crop plants, farm animals, and microorganisms.

By mid 1998, the committee had received 86 applications, of which 75 were for field testing of transgenic crops. Permission for 53 of the applications was granted for commercial production, environmental release, or small-scale field-testing (Chinese Society of Agricultural Biotechnology 1998a, b). The crops used for transgenic research were rice, wheat,

maize, cotton, tomato, pepper, potato, cucumber, papaya, and tobacco. Traits targeted for improvement included pest- and disease resistance, herbicide resistance, and quality improvement. In a few cases, transgenic crops have been grown for large-scale commercial production. The area planted to transgenic crops is expected to increase rapidly in the next few years.

E. Constraints

Many constraints still hinder the large-scale research and use of transgenic crops in the PRC. One of the major constraints relates to intellectual property rights (IPR). The PRC does not yet have effective IPRs for large-scale biotechnology research to develop transgenic crops. Most of the transgenic crop plants developed so far involve complex IPR issues. There is a major shortage of experts with knowledge and experience in dealing with IPR issues. Scientists and breeders do not fully understand IPRs, which are often not recognized and honored. The PRC urgently needs help in training people in IPRs.

Another major constraint is the lack of extension mechanisms to take the products of biotechnology research to farmers. The PRC once had a network system to dispense agricultural technologies, seeds, and other related materials. But with the development of a market economy, the old distribution systems are gradually losing their effectiveness and are now evolving into profit-driven seed companies undergoing privatization. This may be a good movement in itself, but it may take several years for the system to become effective because of uncertain funding. Governmental support goes mainly to research with little left to support initiatives and startups of seed companies.

There are also a number of scientific and technical constraints to the application of technology in crop improvement. One is the lack of understanding of the mechanisms governing the traits important in crop improvement. Drought causes severe yield loss worldwide, and it will continue to be among the most damaging stresses in crop production. Drought tolerance as a trait, however, has not been well defined. It is still not clear what aspects of plant morphology or physiology are most important for drought tolerance.

There is also a need for more germplasm. Germplasm has not been found for a number of important traits such as resistance to fungal

diseases and resistance to a number of pests in crop species (for example, sheath blight of rice, scab disease of wheat, and yellow wilt of cotton). These have become devastating diseases worldwide, as have borer insects of a number of crops. International collaboration, coordinated by the international agricultural research centers, may have a crucial role to play in germplasm identification, exchange, and use.

F. Conclusions

Recent developments in genome mapping and genetic engineering have provided a knowledge base, identified germplasm resources, provided useful genes, and offered effective tools for crop improvement. Integration of the knowledge, the tools, and the genetic resources into breeding programs will greatly increase the efficiency of varietal development.

It is expected that MAS will play a major role in future genetic improvement of many crops. That is not only because the technique itself has proved to be a highly efficient tool for speedy and precise selection, but also because it possesses several distinct advantages. First, it does not require the isolation of the targeted gene, which often takes many years and massive resources to accomplish. Second, most of the gene constructs, such as those commonly used in many transformation studies, are now covered by IPRs and therefore are not freely available for varietal development. Third, the progeny developed by MAS in general does not suffer from adverse effects such as over- or underexpression and transgene silencing, which are now frequently reported with transgenic plants. The performance of the progeny resulting from MAS is therefore much more predictable than those from transformation. The large number of genes that have been precisely tagged and mapped will provide a rich source for MAS in breeding.

The most common practice for obtaining new genes is map-based cloning. Molecular markers that are closely linked to genes of interest can serve as the starting point for cloning the genes following the map-based cloning approach. It is anticipated that the process of gene isolation using this approach will be greatly accelerated with advances in the international effort in DNA sequencing. It is highly likely all the genes that are accurately mapped with closely linked markers can be quickly isolated with the availability of the sequence information.

Biotechnology will soon play a major role in crop improvement in the PRC. The area planted to cultivars developed using biotechnology will increase steadily in the years to come. Biotechnology will contribute significantly to food production and food security in the new century.

APPENDIX 4 AGRICULTURAL BIOTECHNOLOGY IN INDIA⁵

In 1980s the Government of India considered the need for creating a separate institutional framework to strengthen biology and biotechnology research. Modern biological research is supported by these scientific agencies: Council of Scientific and Industrial Research (CSIR), Indian Council of Agricultural Research (ICAR), Indian Council of Medical Research (ICMR), Department of Science and Technology (DST), and University Grants Commission. Biotechnology was given an important boost in 1982 with the establishment of the National Biotechnology Board. Its priorities were human resource development, building infrastructure and facilities, and supporting research and development (R&D) in specific areas.

The success and impact of the National Biotechnology Board prompted the Government to establish a separate Department of Biotechnology (DBT) in February 1986. There have been major accomplishments in basic research in agriculture, health, environment, human resource development, industry, safety; and ethics.

A. Basic Research Platform

Basic research is essential on all aspects of modern biology including development of the tools to identify, isolate, and manipulate individual genes that govern specific characters in plants, animals, and micro-organisms. Recombinant DNA (rDNA) technology is the basis for these new developments.

Areas of biosystematics using molecular approaches; mathematical modeling; and genetics, including genome sequencing for humans, animals, and plants, will continue to have priority. The impact of genome sequencing is increasingly evident in many fields. In the plant genome area, the sequencing of *Arabidopsis* and the rice genome will soon be completed, and cataloging and mapping of all the genes in these species will be done.

⁵ See Sharma (2000).

There have been major achievements in basic bioscience during the last decade in India, where there is expertise in practically all areas of modern biology. Institutions under CSIR, ICMR, ICAR, DST, and DBT have established a large number of facilities where most advanced research work in biosciences is being done. Considerable success has been achieved in the identification of new genes, development of new drug delivery systems, diagnostics, recombinant vaccines, computational biology, and many related areas.

B. Agricultural Biotechnology

The post Green Revolution era is merging with the gene revolution for increasing crop productivity and improving quality. The exploitation of heterosis and development of new hybrids (including apomixis), genes for resistance to or tolerance for biotic or abiotic stress, developing planting material with desirable traits, and genetic enhancement of all-important crops will dominate the research agenda. Integrated nutrient management and development of new biofertilizers and biopesticides are important for ensuring sustainable agriculture, soil fertility, and a clean environment. Stress biology, marker-assisted breeding programs, and studying important genes will continue as priorities.

In India, at least six genes have been cloned and sequenced. Regeneration protocols have been developed for citrus, coffee, and mangrove species. New types of fertilizers and new biopesticide formulations, including mycorrhizal fertilizers, have been developed. Research to develop new transgenic brassica, mungbean, cotton, and potato is well advanced.

Industries have also shown a keen interest in the options of biotechnology and are participating in field trials and pilot-level production. Two successful tissue culture pilot plants in the country, one at Tata Energy Research Institute in New Delhi and the other at National Chemical Laboratory in Pune, are now functioning as micropropagation technology parks. This has given new direction to the plant tissue culture industry. The micropropagation parks serve as a platform for effective transfer of technology to entrepreneurs, including training and the demonstration of technology for mass multiplication of horticultural crops and trees. Considerable progress has been made with cardamom and vanilla, both important crops. Cardamom yield has increased 40 percent using tissue-cultured plants.

The livestock population has provided a *White Revolution*, with 80 percent of the milk in India coming from small and marginal farms. This has had a major social impact. A diverse infrastructure has been established to help farmers in the application of embryo transfer technology. The world's first in vitro fertilized buffalo calf (pratham) was born through embryo transfer technology at the National Dairy Research Institute, Karnal. Multiple ovulation and embryo transfer, in vitro embryo production, embryo sexing, vaccines, and diagnostic kits for animal health have also been developed. Cost effective, environmentally safe waste recycling technologies are being generated. The animal science area is also generating many avenues for employment.

C. Food Security

Food security is an area in which biotechnology offers major inputs for healthier and more nutritious food. Millions of people are malnourished, and vitamin A deficiency affects 40 million children. There are also serious deficiencies of iodine, iron, and other nutrients. A recent UNICEF report on food and nutrition deficiencies in children describes this as a "silent, invisible emergency with no outward sign of a problem." Every year over 6 million children under the age of 5 die in India. More than half of these deaths result from inadequate nutrition.

With the advent of gene transfer technology, there is hope for achieving higher productivity and better quality, including improved nutrition and storage properties of food. There are also possibilities to ensure adaptation of plants to specific environments, to increase plant tolerance for stresses, to increase pest- and disease resistance, and to achieve higher prices in the marketplace. Genetically improved foods will have to be developed under adequate regulatory processes with full public understanding. There is also a need to ensure the safety and proper labeling of genetically improved foods so consumers can identify them and choose whether or not to use them.

D. Plant Biotechnology

With more than 47,000 species of plants and two hot spots of biodiversity, 8 percent of the total biodiversity of the earth is available in

the Indian subcontinent. The bioresource and biodiversity constitute the mainstay of the economy of the poor people, and special emphasis is required for plant biotechnology research.

The isolation of abundant proteins in genes, combining molecular genetics and chromosome maps, and a much better understanding of the evolutionary relationship of the members of the plant kingdom point to the potential of plants becoming the major source of food, feed, fiber, medicine, and industrial raw materials. Molecular fingerprinting and the application of genomics and proteomics to plant improvement will allow transfer of important characters from one plant to another. By identifying appropriate determinants of male sterility, the benefit of hybrid seeds may be extended to more crops. Additional research on apomixis would open up such possibilities.

A National Plant Genome Research Centre has been established at Jawaharlal Nehru University. A number of centers for plant molecular biology in different parts of the country were initially responsible for training significant numbers in crop biotechnology. There are possibilities for producing more proteins, vitamins, pharmaceuticals, pigments, bioreactors, oral vaccines, therapeutic antibodies, and drugs. There are promising leads in these areas, and a number of transgenic plants are ready for field trials. Work on developing transgenic cotton, brassica, mungbean, and potato has significantly advanced.

E. Environment

A special area of global concern among the scientific community is environmental protection and conservation, and the need for a policy of sustainable development in harmony with the environment. The Stockholm Conference in 1972, and the UNCED Conference in Rio de Janeiro in 1992, both focused world attention on pollution, biodiversity conservation, and sustainable development. Plants and microbes are becoming important factors in pollution control. World Bank estimates show that pollution cost India almost \$80 billion, in addition to the human cost in sickness and death. Priority research areas include bioindicators, phytoremediation methods, biobleaching, biosensors, and identification and isolation of microbial consortia. Significant work has been done, but developing a more biologically oriented approach toward pollution control would be extremely important. Cleaning up the large river systems

and destroying pesticide residue in large slums in the cities are priorities in which a biotechnological approach would be environmentally sound.

F. Biodiversity

The global environment is regulated by climate changes and biosphere dynamics. Knowledge about biodiversity accumulated in the last 250 years is being used by scientists throughout the world. There are many gene banks, botanical gardens, and herbaria for conserving genetic resources. There are also molecular approaches for plant conservation, including DNA fingerprinting. The totality of gene species and ecosystems has become exceedingly important, not only for understanding the global environment but also for its enormous commercial significance.

Biotechnology is becoming a major tool in conservation biology. Twelve percent of the world's vascular plants are threatened with extinction, 2,000 of them in India. Over 5,000 animal species are threatened worldwide, including 563 Indian species. Biodiversity is under threat, and understanding the scale of destruction and extinction is essential. Questions such as who owns the biodiversity, who should benefit from it, and what are the roles of society and the individual are pertinent.

More research is needed on forests, marine resources, bioremediation methods, restoration ecology, and large-scale tree plantations. Tree plantation total has reached 180 million hectares and may increase substantially in the next decade. Marine resources provide many products including bioactive materials, drugs, and foods items. They must be characterized and conserved.

G. Bioinformatics

The coming together of biotechnology and informatics is paying dividends. Genome projects, drug design, and molecular taxonomy are all becoming increasingly dependent on information technology. The number of genes characterized from a variety of organisms and the number of evolved protein structures are doubling every 2 years. DBT has established a national bioinformatics network with 10 distributed information centers and 35 subcenters.

H. Ethical and Biosafety Issues

Biosafety guidelines for genetically modified organisms need to be strictly followed to prevent harm to human health and the environment. It is important to give clear explanations of the new biotechnologies to the public to allay their fears. New models of cooperation and partnership have to be established to ensure close linkages among research scientists, extension workers, industry, the farming community, and consumers. A three-tier mechanism of institutional biosafety committees has been instituted in India: the Review Committee on Genetic Manipulation, the Genetic Engineering Approval Committee, and state-level coordination committees.

Thus, the aims and objectives are laudable and the tools are available. The new technology does, however, call for appropriate biosafety guidelines. About 25,000 field trials of genetically modified crops have been conducted worldwide. The anticipated benefits are better planting material and savings on inputs. The potential risks include weediness, transgene flow to nontarget plants, and the possibility of the development of new viruses with wider host range to attack unprotected species.

I. Human Resource Development

There are about 50 approved biotechnology masters, postdoctoral, and medical training programs in different institutions and universities covering most Indian states. Short-term training programs, technician training courses, fellowships for study abroad, training courses in Indian institutions, popular lecture series, awards, and incentives form an integral part of human resource development in India. Since 1996, both industry and biotechnology-based programs in research institutions have employed graduates of such training. National Bioscience Career Development Awards have been instituted. Special awards for women scientists, and scholarships to the best students in biology help promote biotechnology in India and give recognition and rewards to the scientists.

Biotechnology-based activities to benefit the poor, and programs for women have been launched. A unique feature is the establishment of the biotechnology Golden Jubilee Park for Women, which will encourage woman entrepreneurs to take up biotechnology enterprises that benefit women in particular. This will also encourage women biotechnologists to develop relevant technologies.

States are taking a keen interest in developing biotechnology-based activities. Uttar Pradesh, Arunachal Pradesh, Madhya Pradesh, Kerala, West Bengal, Jammu and Kashmir, Haryana, Mizoram, Punjab, Gujarat, Meghalaya, Sikkim, and Bihar have started large-scale demonstration activities and training programs.

J. Future Strategy

The Indian Government has made substantial investments in biotechnology research. Bringing Indian biotechnology products to market will require substantial investments from Indian and overseas investors. The worldwide trend is that large companies are becoming major players in developing biotechnology products and in supporting product-related biotechnology research.

In the years ahead, biotechnology R&D should produce a large number of new, genetically improved plant varieties in India, including cotton, rice, brassica, pigeonpea, mungbean, and wheat. Tissue culture regeneration protocols for important species such as mango, saffron, citrus, and neem will lead to major commercial activities. Micropropagation technology will provide high-quality planting materials to farmers. It is hoped that environmentally friendly biocontrol agents and biofertilizer packages will be made available to farmers in such a way that they can produce them in their own fields. The country should be in a position to fully exploit medicinal and aromatic plants on a sustainable basis.

The establishment of ex situ gene banks to conserve valuable germplasm and diversity; and a large number of repositories (referral centers for animals, plants, and microorganisms) should be possible. Information technology and biotechnology together should become a major economic force. It is expected that plants functioning as bioreactors could produce large numbers of proteins of therapeutic value, and many other important items.

To achieve the goal of self-reliance in modern biotechnology R&D, India will require a strong educational and scientific base, clear public understanding of the value of new biotechnologies, and involvement of society in many of these ventures. India has a large research and educational infrastructure comprising 29 agricultural universities, 204 central and state universities, and more than 500 national laboratories and research institutions. It should therefore be possible to develop capabilities

and programs so that these institutions act as regional hubs for the farming community, obtaining direct feedback from farmers about new technological interventions. It will be equally important to establish strong partnerships and linkages with industry, from the time of the discovery until the packaging of the technology and commercialization are achieved.

APPENDIX 5 AGRICULTURAL BIOTECHNOLOGY IN INDONESIA⁶

Biotechnology has been one of Indonesia's strategic technologies since becoming a priority of the National Science and Technology Development Program in 1988. The Ministry of State for Science and Technology established the National Committee of Biotechnology to formulate national biotechnology policy, monitor its implementation, and oversee biotechnology research and development (R&D). The Committee also sets guidelines for and encourages the establishment of bioindustries, and supports biotechnology R&D and human resource development. It also gives directions for the establishment of national biotechnology networks, and for participation in regional and international networks of cooperation on biotechnology.

To implement this policy, a national biotechnology program was formed in 1990. The program includes the production of fine chemicals and pharmaceuticals (antibiotics, amino acids, vitamins); mass production through micropropagation of industrial, horticultural, and forestry plant species; improvement of food crop quality (in particular rice and soybean); improvement of beef and dairy cattle quality through embryo transfer; and production of various diagnostics and vaccines for human and animal disease.

A. Institutional Arrangements

The national biotechnology program is implemented by several *Centers for Excellence*.

- (i) Center for Excellence on Agricultural Biotechnology I, coordinated by the Central Research Institute for Food Crops, and Center for Excellence on Agricultural Biotechnology II, coordinated by the R&D Center for Biotechnology (LIPI), both in Bogor.

⁶ See Dart et al (2001).

- (ii) Center for Excellence on Health Biotechnology, coordinated by the Medical Faculty of the University of Indonesia in Jakarta.
- (iii) Center for Excellence on Industrial Biotechnology, coordinated by the Agency for Technology Assessment and Application (BBPT), in Jakarta.

Each of these centers is tasked to set up a network of institutions active in its particular field. The Government of Indonesia also has established Inter University Centers on Biotechnology in three universities: Bogor Agriculture University, Bogor, focused on agriculture biotechnology; Bandung Institute of Technology, Bandung, focused on industrial biotechnology; and Gadjah Mada University, Yogyakarta, focused on health biotechnology. These centers were established with the assistance of a World Bank loan in the higher education sector.

B. Competitive Grants in Biotechnology

The Government also revitalized the National Research Council. The Council sets biotechnology priorities each fiscal year and invites scientists from universities and public and private research institutes to submit proposals. A panel of experts evaluates the proposals and recommends studies to be funded to the National Planning Board and the Ministry of Finance.

For the last 7 years, the Government has consistently supported biotechnology research through these competitive research grants. Through this scheme, research activities have increased significantly in quantity and quality. In addition, the Department of Education and Culture also provides funding for university research.

The major institutions involved in biotechnology research are universities and R&D centers of departmental and nondepartmental bodies. Various private companies also conduct biotechnology research. The main institutions and their priorities are listed in Tables A5.1 - A5.3

Table A5.1: University Faculties with Major Activities in Agricultural Biotechnology In Indonesia

University	Location	Field of Study
Faculty of Pharmacy, University of Airlangga	Surabaya	Plant cell cultures, biotransformations with plant cells, rat hepatocyte cultures.
Food and Nutrition Development and Research Center	Yogyakarta	Biotechnology preservation, lactic acid bacteria, cell fusion among <i>Aspergillus</i> strains, monoclonal antibodies for aflatoxin.
Inter University Center for Biotechnology of ITB	Bandung	Microbial fermentation, enzyme technology, genetic engineering, biological wastewater treatment.
Faculty of Agriculture University of Gadjah Mada	Yogyakarta	Baculo virus detection, CPVD-free citrus seedlings, PCR technology, ZMS coat protein genetics for virus-free soybean stocks, food biotechnology.
Inter University Center for Biotechnology IPB	Bogor	Increase of plant productivity by tissue culture, embryo transfer, microbial biotechnology, waste treatment, culture collection.

Source: Schmid et al (1995).

C. Future Biotechnology Policy

Despite the economic crisis of 1997, biotechnology remains a high priority in Indonesia, although the focus and direction have been adjusted to the current economic conditions. The first priority is to apply existing biotechnologies for product(s) in response to the needs of the people, especially in food production, traditional medicine, and value-added agricultural products for import substitution and export. The second priority is strategic research in response to the rapid development of biotechnology for long-term investment and to improve national capabilities in biotechnology.

To implement the above strategies in biotechnology development, national programs need to be pursued.

Table A5.2: Research Institutes Concerned With Agricultural Biotechnology in Indonesia

Institution	Location/Supervision	Target
Indonesian Sugar Research Institute (P3GI)	Pasuruan/Department of Agriculture	Dextranase, xathan gum, sugarcane breeding, waste-water treatment, genetic engineering techniques.
Central Research Institute for Food Crops, Laboratory of Plant Biotechnology	Bogor/Department of Agriculture	Molecular genetics of rice diseases, cell and tissue culture, nitrogen fixation, bio-fertilizers, bioconversion.
Marihat Research Center	Pematang Siantar/Department of Agriculture	Tissue culture on cocoa, rattan, vanilla, oil palm, etc.
Research Institute for Animal Production (Baliknat)	Ciawi-Bogor/Department of Agriculture	Feed improvement using fermentation, mannase, embryo transfer, phytase, cassava protein.
Research Institute for Veterinary Science (Balivet)	Bogor/Department of Agriculture	Cloning of veterinary toxins, veterinary immunology, monoclonal antibodies.
Institute for R&D of Agro-based Industry	Bogor/Department of Industry	Industrial biotechnology, fermentation of soybean curd whey, food quality control.
Center for Assessment and Application of technology (BPPT)	Jakarta/BPPT	Antibiotic production; plant, fish and livestock production; vitamin, enzyme, and amino acid production.
R&D Center for Applied Chemistry-Indonesian Institute of Sciences (LIPI)	Bandung/LIPI	Bioconversion of solasodine, wastewater treatment, fermentation, tempeh.
R&D Center for Biotechnology-Indonesian Institute of Sciences (LIPI)	Cibinong-Bogor/LIPI	Fermentation and enzyme technology for production of enzymes and biocatalysts, plant biotechnology(genetic analysis and transformation), embryo (production/preservation/manipulation/transfer technology), aquaculture, natural products.

Source: Schmid et al. (1995).

Table A5.3: Private Companies Active in Biotechnology in Indonesia

Company	Location	Ownership	Product
Perum Bio Farma	Bandung	State Enterprise	Vaccines, sera, diagnostics
PT Kalbe Farma	Jakarta	Indonesian	Pharmaceuticals, diagnostics
PT Meiji Indonesia Pharmaceutical Industries	Jakarta	Japanese	Antibiotics
PT Rhone-Poulenc Indonesia Pharma	Jakarta	French	Pharmaceuticals, vaccines
PT Sandoz Biochemie Farma Indonesia	Jakarta	Swiss	Antibiotics
Pusat Veterinaria Farma	Surabaya	State Enterprise	Vaccines, antigens
PT Sasa Inti	Probolinggo	Indonesian	Glutamic acid
PT Ajinomotto	Mojokerto	Japanese	Glutamic acid
PT Miwon Indonesia	Gresik	Korean	Glutamic acid
Pt Indo Acidatama	Surakarta	Indonesian	Ethanol
Perusahaan Daerah Aneka Kimia	Surabaya	State Enterprise	Ethanol
Rhizogin Indonesia	Jakarta/Bogor	Indonesian	Rhizobium starter cultures

Source: Schmid et al. (1995).

- (i) **Immediate Application of Existing Technologies.** The use of national capabilities and facilities for producing health products and diagnostics kits, including kits for diseases common to tropical countries, is important. Other applications are embryo transfer to increase the number of improved cattle to meet the demand for meat and milk. Finally, increasing yields of staples such as rice and soybean is of great importance to the country.
- (ii) **Strategic Research.** Strategic research programs to position Indonesia at the leading edge of global market competition

is important for the country's future. Strategic research programs should be based on the country's competitive advantages, e.g., genetic resources. Finding new drugs, genetic improvement of agricultural commodities (food crops, fruits, animals, etc.), marine biotechnology, and environment biotechnology (bioremediation) are priority areas.

- (iii) **Increase Participation of Private Companies.** Indonesia will not be able to achieve significant bioindustry development without the participation of the private sector. As a new emerging technology, biotechnology is a high-risk business. To attract venture capital for the development of biotechnology industries requires finding excellent entrepreneurs and managers.
- (iv) **Human Resource Development.** The major constraint in biotechnology development is the limited number of qualified researchers in the country. The Indonesian Government needs to commit itself to providing facilities and funding for continuous development of human resources.

Various strong research groups being formed. That should lead to the rapid development of collaboration with the international scientific community and attract funding from international funding agencies. Linkages with private sector capabilities will be increasingly important.

D. Future Opportunities from Biodiversity

Indonesia, the largest archipelago in the world, comprises at least 47 different ecosystems. About 17 percent of all living creatures in the world are found in Indonesia, including 10 percent of all flowering plants, 12 percent of mammalian species, and 25 percent of reptile species. This rich biological diversity should be a competitive advantage to the country. It is one that has to be preserved.

With the advancement in biological sciences, particularly in molecular genetics, the potential gene(s) from the rich biological resources could be studied, isolated, amplified, preserved, and used. Biotechnology should have a great potential for Indonesia in agriculture, industry, health, and the environment.

E. Biosafety Regulations

Biosafety regulation has existed in Indonesia since 1997, when the Ministerial Decree on Genetically Engineered Biotechnology Products was promulgated and a committee for biosafety was formed. The committee is supported by a team of experts in plant biotechnology representing national institutes and universities. The technical team formulated a series of general and specific guidelines for the release of genetically engineered plants, microbes, fish, and cattle.

The scope of the decree was broadened in 1999 to cover plantation and forestry plants and food products, which were not included in the original. To fulfill the need for wide coverage of the regulations, the decree was revised in 1999 by the collective decree of four ministries (Ministry of Agriculture, Ministry of Estate Crops and Forestry, Ministry of Food, Ministry of Health). Committee membership and technical team membership were expanded to represent different parties. The guidelines for food safety of genetically modified products were released in 2000.

Indonesia has not yet released any transgenic material. Six applications have been reviewed. Bt maize, and cotton, and Roundup-ready soybean, maize, and cotton have gone through the biosafety committee and are now being reviewed for plant variety release.

F. Intellectual Property Rights

Indonesia enacted a patent law in 1989 that came into force in 1991. With respect to biotechnological invention, it provided that no patent could be granted for any process for the production of food, drinks for human or animal consumption, new plants, or animals or their products. The Act was revised in 1997 in accordance with World Trade Organization regulations that permitted the patenting of such biological products.

APPENDIX 6 AGRICULTURAL BIOTECHNOLOGY IN MALAYSIA⁷

A. Introduction

The agricultural sector has contributed substantially to the growth and development of the Malaysian economy. This has created a rich economic base to promote the rapid development of the industrial and manufacturing sectors, which has taken place since the mid 1980s. Structural change in the economy between 1985 and 1995 have seen the relative contribution of the agriculture sector to employment generation decline from 31.3 percent to 19 percent and export earnings from 36.7 percent to 19.2 percent. Concomitantly, the sector has been confounded by new issues and challenges, in particular an acute labor shortage leading to the employment of immigrant workers, limited availability of suitable land, and an ever-increasing cost of production from intersectoral competition for resources. Compounding all these issues is the intense competition in the global market resulting from trade liberalization.

The recent financial crisis in the country and the region has also exposed the country's vulnerability to a possible food crisis as the cost of food has risen under depreciation of the Ringgit (RM). Food import bills have steadily escalated from RM3.5 billion in 1985 to RM7.7 billion in 1995 to RM10 billion by 1997. The RM was pegged at the rate of RM3.80 to the \$ in mid 1998. Meanwhile, the population has increased from 17.6 million in 1991 to a current level of 22 million (National Census 2000). The higher demand for food has led to an increase in food prices.

With competition for land use, the rural sector continues to experience problems of low productivity and holdings too small to be economically viable. Labor shortages and low commodity prices have further led to substantial idle or abandoned agricultural holdings away from the urban centers. It is estimated that there are about 400,000 ha of idle agricultural land in Malaysia.

Malaysian agriculture is also faced with greater competition with full implementation of agreements under the World Trade Organization and the Common Effective Preferential Tariff (CEPT) scheme of the

⁷ See Nair et al (2001).

Association of Southeast Asian Nations (ASEAN) Free Trade Area. Main export commodities such as rubber and oil palm face increasing competition from emerging lower-cost products and continue to face discriminatory tariff and nontariff barriers.

The Third National Agricultural Policy (NAP3), launched in December 1999 for the period 1998-2010, addresses the issues and challenges mentioned above. The overriding objective is to maximize income through efficient and optimal use of resources. It formulates new strategic approaches and policies to enhance the economic contribution and growth of the agricultural sector. Among the major developments are the following:

- (i) To integrate agriculture and forestry development using an agroforestry approach to provide a large, productive base to both sectors while optimizing resource usage.
- (ii) To encompass a product-based approach for commodity development based on market demand, preferences, and potential.

B. Development in Biotechnology

One goal of NAP3 is to strengthen the economic foundation for the development of agrobiotechnology and specialty natural products industries. Government support and commitment for strong research and development (R&D) and human resources development (HRD) programs will be intensified to build a pool of world-class researchers and technical personnel. The current incentive framework to accelerate establishment and development of these industries will be continued. That includes funding for research facilities and the setting up of more incubation centers.

Significant support for biotechnology began in the mid 1980s when the Government first allocated substantial R&D funds to public institutes under a national program for Intensification of Research in Priority Areas (IRPA). IRPA coordinates the Ministry of Science, Technology and the Environment (MOSTE). In the 1980s, R&D in agricultural biotechnology was carried out in R&D institutions, local universities, and in the private sector. The main activities were:

- (i) Micropropagation.
- (ii) Microbial fermentation for the production of *koji* for soy sauce and other fermented foods.
- (iii) Solid state fermentation for producing compost.

The second phase began in the 1990s with substantial support for high-end advanced biotechnologies involving genetic manipulation of plants and microbes. Molecular biology and other specialized biotechnology laboratories were set up in many public sector R&D institutions and universities.

To manage R&D in biotechnology, an ad hoc National Biotechnology Working Group was initially formed under MOSTE. In 1995 the National Biotechnology Directorate (NBD) was established as a more permanent structure within MOSTE. This was an important turning point as NBD took over the management of biotechnology research, development, and commercialization in the country. Today NDB spearheads Malaysia's progress toward becoming an important center for biotechnology industries.

1. National Biotechnology Directorate

NBD has two major objectives:

- (i) To initiate and develop collaboration with research organizations and industries that will lead to commercialization of biotechnologies and promote sustainable economic development.
- (ii) To build national research capability in biotechnology.

Seven biotechnology cooperative centers (BCC) have been formed under NBD to support the major biotechnology-based activities in the country: plant, animal, food, biopharmacy, environmental/industrial, molecular biology, and medical biotechnologies.

The centers are located in nine institutions and seven universities identified as having the best infrastructure to coordinate the activities expected of a BCC (Table A6.1). Agrobiotechnology R&D is mainly covered under the plant and animal BCCs, but is also represented within the food, environmental/industrial, and molecular biology BCCs. Information on R&D activities at the organizations listed in Table A6.1 can be accessed through the NBD home page (<http://nbd.mastic.gov.my>).

Table A6.1: Malaysian Research and Development Organizations in Biotechnology

Institutes	Forest Research Institute Malaysia Institute for Medical Research Malaysian Agricultural Research and Development Institute Malaysian Cocoa Board Malaysian Institute for Nuclear Technology Research Malaysian Palm Oil Board Malaysian Rubber Board Standard and Industrial Research Institute of Malaysia Veterinary Services Department
Universities	Universiti Kebangsaan Malaysia Universiti Malaya Universiti Malaysia Sarawak Universiti Malaysia Sabah Universiti Putra Sarawak Universiti Sains Malaysia Universiti Teknologi Malaysia

Source: Nair and Abu-Bakar (2001).

2. Policy and Priority

The policies currently guiding biotechnology development are mainly based on two documents: the Third National Agriculture Policy (1998-2010) and the Second Industrial Master Plan.

- (i) The Third National Agriculture Policy (1998-2010) was formulated with the main objectives of: (a) improving food security, (b) increasing productivity and competitiveness of the agriculture sector, (c) strengthening relationships with the other sectors, (d) establishing new industries, and (e) conserving and using natural resources.
- (ii) The Second Industrial Master Plan has identified the following areas for exploitation under the agriculture sector: (a) agro-based and food products industry, (b) fruits and vegetables, (c) floriculture, (d) chemical industry, and (e) natural products.

Under the Seventh Malaysia Plan (1995-2000), agrobiotechnology research has focused on (i) genetic engineering for crop improvement,

disease and herbicide resistance, and value-added products; (ii) increased rice yields; (iii) increased shelf-life of fruits and flowers; (iv) improved flower color; (v) cell culture/bioreactor for producing chemicals; (vi) tissue culture; (vii) vaccine development and livestock production; and (viii) advanced reproductive biotechnology for improved beef cattle production.

3. Human Resource Development

Human resource development is of utmost importance for the success of biotechnology. Great emphasis is placed on developing sufficient human capital to support this high-technology, knowledge-based discipline. Local universities offer degree and postgraduate programs and conduct short training courses in many important biotechnology areas. A special National Science Foundation (NSF) has been created to sponsor postgraduate studies, especially in key areas such as bioinformatics, which lack key personnel. These and other government-sponsored fellowships are available through NBD for short courses locally or temporary postings to overseas laboratories.

4. Research and Development

Biotechnology R&D has been conducted primarily in nine government research institutes and seven universities (Table A6.1). More recently, with attractive tax-incentives from the Government, there is growing collaboration with the private sector. Under the Seventh Master Plan, 11 top-down programs projected to be of national importance were identified by NBD and approved for IRPA funding (Table A6.2).

Another key development has been the funding of 11 developmental projects (Table A6.3) by NBD. These projects, arising from results of earlier projects under IRPA funding, were deemed to be at the precommercial stage and thus approved for funding with NBD grants.

A number of international bilateral collaboration programs in biotechnology have also begun (Table A6.4); three others are in the pipeline.

Table A6.2: Malaysian Top-Down Biotechnology Projects

Projects ^a
Molecular Manipulation and Engineering of Rice for Resistance to Diseases (tungro and sheath blight)
Improvement of Orchids and Tulips Through Genetic Engineering
Construction of Recombinant Bacteria for Vaccine Delivery
Development of DNA Markers for Identification of Color Varieties and Sex in Tiger Barbs
Molecular Approaches to Determination of Biomarkers for Diseases and Disease Susceptibility and Development of Appropriate Techniques for Diagnosis Interaction of Tumor, Host and Virus Factors in Growth and Progression of Malignant Lymphomas
Production of Sodium Citrate by Fermentation of <i>Aspergillus niger</i> Using Sago Hydrolysate
Development of an Integrated Landfill Treatment System Using Microbial Processes
Biodiversity Prospecting and Screening
Exploration of Gene Function and Organization During Developmental Events
Studies on Gene Structure and Function: Cloning, Sequencing, Expression, and Modification of Selected Genes from Bacteria and Fungi
Application of Biotechnology for the Production of Flavor Ingredients
Utilization of Microorganisms and Enzymes for the Production and Improvement of Starch-Based Foods and Food Ingredients

DNA = deoxyribonucleic acid.

^aFunded by Government of Malaysia Intensification of Research in Priority Areas Program. Source: Nair and Abu-Bakar (2001).

Table A6.3: Developmental Research Projects in Malaysia

Year	Project Title
1997	Scale-Up Production and Market Testing of Clarified Tropical Fruit Juices Semi-Scale Production of Goniothalamine Through Bioreactor Propagation for Clinical Trial
1998	Commercial Production of Bacterial Inoculants as Biofertilizer and Enhancer Further Improvement of Pasteurella Spray Vaccine Against Pneumonic Pasteurellosis in Sheep and Goat Commercial Production of a Local Live Infectious Bronchitis (UREMIA) IB (U) Vaccine Development of Fermentation Biotechnology for the Commercial Production of Malaysian Isolates of <i>Bacillus sphaericus</i> , a Mosquito Control Agent
1999	Production of Molecular Biological Reagents for Local Market Commercialization of <i>Brugia malayi</i> Research and Development Findings Into Diagnostic Kit Commercial Application, State of the Art Biotechnological Advancements for Clonal Propagation of Bananas Commercial Environmental-Controlled Production of Tulips and Ornamental Bulbs Development of Prototype Kit for the Rapid Diagnosis of Typhoid Carrier

Source: Nair and Abu-Bakar (2001).

**Table A6.4: Malaysian Bilateral Collaborative Projects
In Agricultural Biotechnology**

Partners	Project Title
Malaysia – Thailand	Cryopreservation of Bovine Oocytes and in vitro Produced Bovine Embryos Development of Biosensor for Application in Environment and Food Industry
Malaysia – Hungary	Genetic Engineering of Chili for Disease Resistance Recombinant Vaccine for Infectious Bovine Diseases
Malaysia – New Zealand	Properties and Application of Starch-Based Food Ingredients Produced Through the Use of Microbial and Enzyme Technologies Development of Transformation and Regeneration System for Genetic Manipulation of Flowering and Insect Resistance in Teak (<i>Tectona grandis</i>) Advanced Animal Reproductive and Embryo Transfer Technologies to Produce High Quality Animals from Sexed Embryos
Malaysia	Massachusetts Institute of Technology Biotechnology Partnership Programme Subprogram: Oil Palm Biotechnology Subprogram: Natural Product Discovery

Source: Nair and Abu-Bakar (2001).

5. Some Achievements to Date

The achievements in agribiotechnology during the past decades can be summarized as follows:

- (i) Tissue culture and micropropagation protocols for the regeneration of several useful tropical forest plants and woody trees, as well as plantation crops and horticultural crops, have been developed in public and private research laboratories.
- (ii) Good progress is being made in developing genetic manipulation and transformation systems, and inserting genes of interest into several plants including rice, papaya, banana, orchid, pineapple, oil palm, and rubber.

- (iii) Many genes useful for crop improvement have been isolated and cloned, and their gene sequences deposited in international gene banks.
- (iv) A number of patents have been obtained; others are pending.
- (v) Facilities are being built to house the increasing number of transgenic plants being produced.
- (vi) NBD is taking the initiative to develop infrastructure for R&D in genomics and proteomics to facilitate further understanding and cloning of new useful genes.

Rice. The transformation system for local rice varieties has been established. Transgenic rice containing the coat-protein gene for the tungro virus has been developed. Glasshouse screening has been completed and field trials are being planned for 2001. Transgenic rice with herbicide resistance has also been produced and is currently in glasshouse trials. Transgenic rice resistant to sheath blight disease is being developed. MARDI's rice biotechnology project was part of the Rockefeller Foundation Network on Rice Biotechnology that has just ended. Rice biotechnology is still being given top priority through top-down funding.

Papaya. Work on gene cloning for papaya ringspot virus (PRSV) coat protein gene and the ethylene gene ACO (1-aminocyclopropane-1-carboxylic acid oxidase), for shelf-life, started concurrently with the development of the transformation system for papaya. Now transgenic papaya containing the shelf-life gene are being produced. Field trials are planned for late 2001. Transgenic papaya containing PRSV coat protein construct are being produced and analyzed. Both papaya projects are part of the Papaya Biotechnology Network of Southeast Asia under the auspices of the International Service for the Acquisition of Agri-Biotech Applications. The project to develop papaya with increased shelf-life using the ethylene gene ACO is carried out in collaboration with the University of Queensland with funding by the Australian Centre for International Agricultural Research.

Orchid. The ethylene gene ACO, related to the senescence of orchid, has been cloned along with genes involved in flower color. The transformation system for *Dendrobium* has been established and transgenic plants containing antisense ACO have been produced.

Chili. Coat protein gene to cucumber mosaic virus (CMV) has been cloned. A successful transformation system for chili is yet to be developed.

C. Biosafety Rules and Regulations

A survey on biosafety practices was conducted among biotechnologists in the country by the National Biotechnology Working Group on Agricultural Biotechnology. Based on this survey and a series of workshops, the National Guidelines for Biosafety were officially launched by MOSTE in January 1997. The guidelines are still followed on a voluntary basis.

Drafting for a biosafety law started in 1998. The draft biosafety law has been submitted to the Attorney General's office for approval. National consultation with interested stakeholders has begun with a series of meetings and discussions. The group consists of various government agencies, ministries, R&D institutes, academia, and the private and public sectors including nongovernment organizations. It is hoped that the bill will be ready for Parliament by mid 2001. A new law for food and feed, which will cover genetically modified organisms, will be compatible with the biosafety law.

The Genetic Modification Advisory Committee (GMAC) Malaysia acts as an advisory body to MOSTE on technical matters. GMAC members come from academia, R&D institutions, Ministry of Health, and Ministry of Agriculture.

No field trial has been approved yet in Malaysia. Applications for field trials of oil palm and rice have been submitted to GMAC for approval. Importation into Malaysia of herbicide tolerant soybean was approved after thorough review by the GMAC.

D. Future Prospects

The future looks good for agrobiotechnology in Malaysia, especially with strong endorsement by the Government, which recognizes it as a high-end technology to be fully exploited in the twenty-first century. Funding for biotechnology research is projected to increase even more and will also include more from the private sector and international agencies.

R&D in modern biotechnology has come of age. Expansion of infrastructure and facilities and building of human capital is progressing well. Collaborative research between the public and private sectors is expected to increase.

Many genes have been successfully cloned and plant transformation systems developed. Studies on the function and control of relevant genes will be analyzed, assisted by information from genomics and proteomics projects. With the increasing number of transgenic crops with useful genes, crop improvement and value-added products will soon be a reality.

Three new national institutes will be established in agricultural biotechnology, genomics, and pharmaceuticals/neutraceuticals.

Communication and networking through systems such as NABBINET should be used to help rural farmers reap the benefits of agrobiotechnology.

Serious attention will be given to biosafety, risk management, and the responsible exploitation of biotechnology products to ensure a safe and healthy environment and conservation of natural resources. Once the biosafety law is in place, it will encourage more bilateral collaboration with private and public organizations abroad, and attract many more biotechnology companies to Malaysia.

APPENDIX 7 AGRICULTURAL BIOTECHNOLOGY IN PAKISTAN⁸

A. Entry of Pakistan Into the Biotechnology Era

The vast potential of biotechnology was formally recognized in 1981 when the first course on recombinant DNA technology was organized by the Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad. That same year the Ministry of Education approved the establishment of the Centre of Excellence in Molecular Biology (CEMB) on the campus of Punjab University. The newly established biotechnology center was joined by the National Institute for Biotechnology and Genetic Engineering (NIBGE) in 1983. The institute aims to develop, adopt, and apply innovative and modern research in agriculture, industry, health, and the environment.

B. Research Institutions Involved in Agricultural Biotechnology

Of 102 research centers related to agriculture, most carry out traditional biotechnology (tissue culture, biofertilizer). High-tech agriculture biotechnology is restricted to only two centers (CEMB and NIBGE). Though the facilities for genetic engineering of crops are excellent, some major weaknesses are inherent in their capabilities. For instance, the lack of consumables (chemicals, enzymes, plasticware) often results in considerable delay in completing experiments.

Although a number of research centers related to agriculture have acquired the capability to use the techniques of traditional biotechnology, the size of the research effort is comparatively small (Table A7.1). Only the production of virus-free potato seed has reached commercial scale.

⁸ See Zafar (2001).

C. Agriculture Biotechnology Programs

Recent developments in plant biotechnology have greatly increased the possibility of crop improvement. It allows the manipulation of genetic material with greater accuracy in a much shorter time than is possible with conventional breeding methods.

Research in agricultural biotechnology can be divided into two broad categories:

- (i) Traditional
 - Fermentation - Biopesticides, biofertilizers
 - Tissue culture - Mass production of disease-free plantlets

- (ii) Modern
 - Molecular breeding - DNA fingerprinting
 - Genetic engineering - Development of crops with novel traits

1. Traditional Biotechnology

a. Biopesticides

The high concentration of chemical pesticides has become a serious concern in recent years. Current trends suggest that the use of chemical pesticides is likely to continue to increase in the near term. There is a growing need to promote the use of alternative methods of crop protection by substituting chemical pesticides with environmentally friendly biopesticides.

Biopesticides are living organisms. Their two most important advantages are: (i) they are target-specific and do not destroy beneficial organisms, and (ii) they do not leave harmful residues. Some of the important biopesticides include parasites, fungi, and baculoviruses. Although the importance of biological control has been known for many years, it is not yet a high priority for government agencies.

b. Biofertilizers

The potential of certain microorganisms to improve the availability of nutrients to crop plants has long been known. In view of the high cost of chemical fertilizers and their adverse effect on the environment, these microorganisms (collectively called biofertilizers) have become increasingly important. They are particularly important in tropical countries whose soils are low in organic matter and essential plant nutrients.

Most biofertilizers are nitrogen fixing in nature; they fix atmospheric nitrogen to ammonia by a complex metabolic process. Broadly speaking, there are two types: symbiotic and free living. Symbiotic biofertilizers are represented by *Rhizobium*. The free-living ones, which can fix nitrogen independently, include *Azotobacter*, *Azospirillum*, blue green algae (BGA), and azolla.

Rhizobium is the most researched and well known biofertilizer. Its role in nitrogen fixation in legumes is well established. Although *Rhizobium* forms a symbiotic association with legume crops naturally, in many cases it is an inefficient nitrogen fixer or it is present in too few numbers to fix sufficient nitrogen for a crop. Of more than 50 mungbean rhizobial strains isolated from different parts of Pakistan, only a few were effective. Artificial inoculation of soil with *Rhizobium* strains to augment nitrogen-fixing can increase crop yield. Under favorable conditions, 200 grams of *Rhizobium* can fix 200-300 kilograms of nitrogen/hectare.

The bacteria *Azotobacter* and *Azospirillum* are commonly found in the rhizosphere of cereals, grasses, and vegetables. In addition to fixing nitrogen, they produce growth-promoting substances and antibiotics. As in the case of *Rhizobium*, they can be applied as seed inoculants, or the roots of seedlings can be dipped into a suspension before transplanting. Reports suggest that, depending on the crop and in favorable conditions, they can supply 25-50 percent of the nitrogen requirement.

The other important, free-living nitrogen-fixing agents are BGA and the water fern azolla. Both prefer standing water for growth and are suitable for use as a source of nitrogen for rice.

Much of the production of biofertilizers is directly or indirectly supported by the Government. An ambitious program on biofertilizers production, begun in 1972 in NIAB, has now been transferred to NIBGE, which produces them commercially. The program has been expanded to the National Agricultural Research Centre, Islamabad, and several provincial institutes.

Table A7.1: Pakistan National

Ministry	Center	Section	Crop
Ministry of Agriculture	NARC, Islamabad	Tissue Culture Biofertilizer	Potato, date palm, banana, chickpea
Ministry of Science and Technology	CEMB, Lahore	Agriculture Biotechnology	Insect-resistant cotton, chickpea, rice Biopesticide
Pakistan Atomic Energy Commission	NIAB, Faisalabad	Mutation Breeding	Tissue culture of rice, chickpea, citrus, lentils
	NIFA, Peshawar	Mutation Breeding	Tissue culture of potato
	AEARC, Tandojam	Mutation Breeding	Sugarcane
	NIBGE Faisalabad	Plant Biotechnology Biofertilizers	Tissue culture of sugarcane, banana Transgenic cotton, rice, Biofertilizers

ADB = Asian Development Bank, Bt = *Bacillus thuringiensis*, CEMB = Centre of Excellence in Molecular Biology, FAO = Food and Agriculture Organization, Govt, the = Government of Pakistan, IAEA = International Atomic Energy Agency, NARC = National Agricultural Research Centre, NIAB = Nuclear Institute for Agriculture and Biology, NIBGE = National

The demand for biofertilizers suffers from three factors: poor and uneven quality, short shelf life, and small contribution to crop yield. Research to optimize production and improve quality is done at a number of centers, although progress has been limited. Work to increase the survival and effectiveness of biofertilizers through genetic manipulation of strains has begun only recently. A significant increase in acceptance of biofertilizers is possible only if these efforts are successful. Otherwise, the contribution of biofertilizers to sustainable agricultural development will continue to be small.

Agriculture Biotechnology Research

Res/PhD	Facilities	Commercial product	Research Funds
15/2	Excellent	Virus free potato seed Bio/date palm	the Govt/FAO/US
17/2	Excellent (Containment facility absent)	Restriction enzymes	the Govt/ADB/ WB/RF
3	Fair		the Govt/ODA/IAEA
1	Poor		the Govt
3	Fair	Sugarcane, banana	the Govt/IAEA/FAO
23/7	Excellent (Containment facility present)	Virus free potato seed Biopower	the Govt/ADBI/AEA/FAO

Institute for Biotechnology and Genetic Engineering, ODA = Overseas Development Administration (UK), PAEC = Pakistan Atomic Energy Commission, PhD = Doctor of Philosophy, Res = researchers, RF = Rockefeller Foundation, US = United States, WB = World Bank.

c. Tissue Culture

Modest tissue culture facilities were developed as early as 1968 in the Botany Department, Peshawar University, and from there spread to nearly every major research institute in the country. Although there is a great scope for mass propagation of disease-free plants in several important vegetatively grown crops (sugarcane, potato, banana, date palm), commercial production has been achieved only in potato. Several small-scale private firms and nongovernment organizations are involved.

2. Modern Agriculture Biotechnology

a. Molecular Breeding

DNA fingerprinting is a powerful technique widely used in conventional breeding programs. This technology is extremely useful in the following areas:

- (i) To evaluate genetic diversity of a specific crop.
- (ii) To identify relationships between species.
- (iii) To aid marker-assisted selection for specific traits to speed the breeding process.
- (iv) To isolate genes of interest by making dense genome maps.

Various international groups have undertaken genome projects for several crops (tomato, rice, cotton, *Arabidopsis*). In Pakistan, a *cotton genome project* was initiated in 1996, the only project of its kind in the country. Some preliminary work carried out at NIAB on rice and wheat is now merged with NIBGE. Earlier efforts by CEMB, Lahore, to initiate restriction fragment length polymorphism studies of brassica were unsuccessful.

b. Genetic Engineering for Crop Improvement

In Pakistan, crop improvement efforts using modern biotechnology started at CEMB in 1985. Genetic engineering of plants followed at NIBGE in 1986. These are the only two centers where genetic engineering is done (Table A7.2). No transgenic plant has so far been released in Pakistan, whether developed locally or imported from developed countries.

The use of biotechnology in crop improvement is comparatively new in Pakistan. Most of it is concentrated on chickpea, rice, and cotton. Research on rice is mainly due to support by the Rockefeller Foundation Rice Biotechnology Project. Cotton is the focus of a recent \$10 million loan of the Asian Development Bank to the Ministry of Food, Agriculture, and Livestock. Although CEMB and NIBGE have obtained transgenic cotton plants, field evaluation is blocked by the absence of biosafety rules. Further delay and uncertainty is expected due to the actual performance of the crop in the field, and difficulties associated with protecting it from use by various seed agencies (public and private). The present research

Table A7.2: Pakistan National Programs on Plant Genetic Engineering

Center	Crop	Trait	Status	Commercial Release
CEMB, Lahore	Cotton, Rice, Chickpea	Bt gene	Transgenic plants	No
NIBGE, Faisalabad	Cotton	Antiviral gene	Transgenic plants at testing stage	No
	Rice	Salt tolerance	Transgenic plants at testing stage	No

Bt = *bacillus thuringiensis*, CEMB = Centre of Excellence in Molecular Biology, NIBGE = National Institute for Biotechnology and Genetic Engineering.

and its potential contribution are hard to assess. Even the most optimistic estimates make it at least 3 to 5 years before plants with desired traits can be produced and used in breeding programs.

D. Policy Planning

Biotechnology has been viewed by government functionaries, political leaders, and leading scientists as a priority for a little over a decade. But there is yet no coherent national policy regarding agricultural biotechnology. Several ministries and organizations initiated biotechnology programs on their own with no apparent coordination. Lack of clear national objectives and priorities resulted in duplication of work and dilution of efforts.

The Pakistan Science Foundation established a Task Force on Biotechnology in 1995 and formulated many recommendations affecting various sectors including agriculture and livestock. Implementation was hampered by a lack of political and financial backing. Recently, the Prime Minister's High Level Commission for Science and Technology, supported by the World Bank (1996-97), called for a standing committee on biotechnology. This report so far has not been presented to any committee of Parliament for consideration.

Multinational companies play a major role in agricultural biotechnology research and development, but it is national governments or the

public sector that must regulate testing, multiplication, distribution, and safety of bioengineered products. Pakistan has yet to draw up a policy or enact legislation covering intellectual property rights, patenting of bioengineered products or processes, or biosafety codes for genetically modified organisms. This regulatory vacuum has been a deterrent to major involvement by multinationals in agricultural biotechnology.

E. Potential Impact of Biotechnology Initiatives

Agricultural biotechnology must be considered a supplement to existing crop improvement programs. It is not a panacea but a technology that, when backed up with other management strategies, is bound to deliver goods in a shorter time. The following are a few national projects that, if seriously pursued, will definitely create an economic impact:

- (i) Mass production of disease-free banana plants.
- (ii) Multiplication of virus-free potato plants.
- (iii) Multiplication of disease-free sugarcane plants.
- (iv) Rapid multiplication of exotic clones of sugarcane.
- (v) Rapid multiplication of female papaya, pineapple, and other economically important fruits and flowers.
- (vi) Development of crops tolerant of biotic or abiotic stresses.
- (vii) Initiation of marker-assisted selection to speed incorporation of desired traits through conventional breeding.

These technologies are well known and being done on a small scale in various national centers.

APPENDIX 8 AGRICULTURAL BIOTECHNOLOGY IN THE PHILIPPINES⁹

In 1997, the combined area devoted to agriculture in the Philippines was 10.3 million hectares (ha), with coconut being the most widely planted crop (4 million ha), followed by rice (3.5 million ha), maize (1.2 million ha), banana (200,000 ha), pineapple (40,000 ha) and others (Bureau of Agricultural Statistics Report, 1997). The country is a major producer of coconut, sugarcane, banana, and pineapple. The export value of sugarcane and coffee has declined considerably in recent years.

More than 70 percent of the population is directly or indirectly dependent on agriculture. Most of the land is owned by small-scale farmers. Increases in population have placed tremendous pressure on agricultural lands. Prime agricultural lands are being converted to resettlement areas and to industrial use.

The Philippines started its biotechnology programs in 1980 with the creation of the National Institutes of Molecular Biology and Biotechnology (BIOTECH) at the University of the Philippines at Los Baños (UPLB). In 1995, three other biotechnology institutes were established within the University of the Philippines (UP) System. They are located in the UP Diliman campus for industrial biotechnology, UP Manila for human health biotechnology, and UP Visayas for marine biotechnology.

BIOTECH continues to provide leadership in agricultural, forestry, industrial, and environmental biotechnology. Other research institutes at UPLB are also doing biotechnology research. Among these are the Institute of Plant Breeding, Institute of Biological Sciences, Institute of Animal Sciences, Institute of Food Science and Technology, and the College of Forestry and Natural Resources. Outside UPLB, other research institutes and centers such as the Philippine Rice Research Institute, Philippine Coconut Authority, Cotton Research and Development Institute, Bureau of Plant Industry, Bureau of Animal Industry, and the Industrial Technology and Development Institute are also involved in biotechnology research and development (R&D).

The type of research undertaken in the Philippines from 1980 to 1999 was mainly conventional biotechnology, with the exception of a

⁹ See De la Cruz (2000).

small amount of work on molecular markers and the development of genetically improved organisms (GIOs) with useful traits (Table A8.1).

In 1998, five high-level biotechnology research projects were funded by the government:

- (i) Transgenic banana resistant to banana bunchy top virus and papaya resistant to papaya ringspot virus.
- (ii) Delayed ripening of papaya and mango.
- (iii) *Bacillus thuringiensis* maize.
- (iv) Marker-assisted breeding in coconut.
- (v) Coconut with high lauric acid content.

About 80 percent of the total annual budget for biotechnology R&D comes from the Government, 15 percent from international development agencies, and 5 percent from the private sector. The private sector is expected to provide more funding in the future as companies see the potential of biotechnology in agriculture.

Table A8.1: Philippine Biotechnology Projects Funded from 1980 to 1999

Type of R&D	Projects (no.)	Percent of total
Biocontrol	55	20.7
Soil amendments	44	16.5
Food/beverage	43	16.2
Tissue culture	52	19.5
Feed component	20	7.5
Enzymes	16	6.0
Diagnostics	7	2.6
Farm waste	4	1.5
Vaccines	3	1.1
Animal reproduction	3	1.1
Molecular markers	12	4.5
GIOs	7	2.6
Total	266	100.0

GIO = genetically improved organism.

Source: Survey conducted by UPLB BIOTECH, 1999.

In 1997, the Agriculture Fisheries Modernization Act (AFMA) became law. The main objective of AFMA is to modernize agriculture including infrastructure, facilities, and R&D. AFMA recognizes biotechnology as a major strategy to increase agricultural productivity. The law states that AFMA will provide 4 percent of the total R&D budget per year for biotechnology during the next 7 years. This allocation provides an annual budget for biotechnology of almost \$20 million. Before AFMA, the annual budget averaged less than \$1 million.

AFMA operates through National Research, Development and Extension (RDE) networks of 13 commodities and 5 disciplines. The 13 commodity networks are rice, maize, root crops, coconut, plantation crops, fiber crops, vegetables/spices, ornamentals, fruit/nuts, capture fisheries/aquaculture, livestock, poultry, and legumes. All of these commodities include biotechnology in their RDE agenda. The five discipline-oriented RDE networks are (i) fishery postharvest and marketing; (ii) soil and water resources; (iii) agricultural and fisheries engineering; (iv) postharvest food and nutrition, social science, and policy; and (v) biotechnology. Biotechnology focuses on upstream (basic) research, which includes work in molecular biology. The commodity networks focus on downstream (applied) research.

The main goal of biotechnology R&D under AFMA is to harness the potential of this cutting-edge technology to increase productivity of all the commodities in the agriculture and fishery sectors. Biotechnology will therefore play a major role in the selection and breeding of new varieties of plants and animals. It will also provide the inputs required such as biofertilizers and biocontrol of pests and diseases. Biotechnology will also be used to produce genetically improved crops with insect- and disease resistance, for accurate diagnosis and control of diseases in plants and animals, for bioremediation of the environment, and for bioprospecting. The benefits derived are intended for the small farmers and fishermen.

The Philippines does not have adequate human resources required for biotechnology R&D. As of 1999, there were only about 250 scientists qualified to do high-level biotechnology R&D. Most of the researchers are affiliated with universities, particularly UPLB.

Adequate laboratory facilities and equipment for upstream biotechnological research exist at a number of institutions in the Philippines including UPLB BIOTECH and UP Diliman, Institute of Biological Sciences, Institute of Plant Breeding, and Philippine Rice Research Institute. There is a need, however, to upgrade most of the laboratories in the country.

A. Future Challenges

Although the Philippines recognizes the tremendous potential of biotechnology, several challenges need to be met before the goals set can be achieved.

Yields of crops and livestock have been declining, while demands are increasing because of the rapid increase in population. Conversion of prime agricultural lands into other uses has placed tremendous pressure on the agricultural sector to increase productivity. Productivity has been affected by poor soil fertility, the incidence of pests and diseases, abiotic stresses such as drought, and climatic factors, especially typhoons. The challenge is to use biotechnology to increase on-farm productivity and yield using minimal inputs.

With impending trade liberalization, the country expects to receive cheap agricultural products from other countries, thus widening its balance of trade deficit. In 1998, the value of Philippine exports was estimated at \$28 billion, while imports were valued at \$29 billion. The challenge is to use biotechnology to produce local products that are highly competitive with those from foreign sources, thereby promoting exports of quality products while reducing imports.

The Philippines is sensitive to the issue of biosafety, having one of the strictest biosafety guidelines in the world regulating R&D and field testing. The challenge is to improve and better implement the current biosafety guidelines, taking advantage of knowledge generated worldwide. Protocols are needed to assess risks of GJOs and to manage any identified risk factors. The Philippines must develop its capabilities to undertake risk assessment and management, based on scientific evidence.

The commercial release of new products must be regulated. At present, none of the regulatory bodies, such as the Bureau of Plant Industry, Bureau of Animal Industry, Fertilizer and Pesticide Administration, Bureau of Food and Drugs Administration, and the Environment and Management Bureau, have policies and guidelines to regulate the commercial release of new genetically improved products. In addition, the institutional support system, such as laboratories and infrastructure, is not in place. The challenge is to create guidelines to regulate commercialization of GJOs, the establishment of support laboratories and infrastructure, and the training of people for these regulatory bodies.

Products of research will not create any measurable impact unless they are transferred to end-users or commercialized. The challenge is to

transfer products to users, particularly to small farmers and fishermen. This requires the proper packaging of the product to attract private investors for eventual commercialization.

Transgenic crops and other genetically improved products may become trade-related issues in the future because of trade liberalization. It is expected that new genetically improved crops will be imported into the Philippines. The challenge is to create public awareness of the benefits and risks of any new product, and assist acceptance of new and beneficial technologies by consumers.

Because the processes, products, and genetic materials used in biotechnology R&D have proprietary considerations, issues of intellectual property protection by patents and plant variety protection will arise. The present Intellectual Property Code of the Philippines allows the patenting of microorganisms, but not plants and animals. Plant varieties will be protected by a *sui generis* mechanism if the plant variety protection bill is passed by both houses of Congress. The challenge is for the country to strengthen its intellectual property laws to provide protection to researchers, discoverers, and investors.

B. Opportunities

Although the Philippines lags behind the industrial countries and its ASEAN neighbors in biotechnology R&D, many windows of opportunity are open. Biotechnology provides the opportunity for researchers to improve plant growth and development, and increase yields by providing for the basic needs of the plant such as biofertilizers and biocontrol agents.

There is the potential for improving crop plants containing genes that provide pesticidal properties; resistance to herbicides; tolerance for pests, diseases, and stress (salt, heavy metals, drought); or combinations of these. Such improved plants are expected to reduce production costs. Once the issues of biosafety regulation and intellectual property have been settled, the country will be open to use such new plant technologies that are now limited to only a few countries.

Marker technologies may help speed the selection and production of more effective hybrids. Most breeding work in the Philippines now uses this technology, particularly in rice, maize, banana, and coconut.

New opportunities are available for livestock biotechnology including the production of vaccines for foot and mouth disease and hemorrhagic

septicemia, for diagnostics, and for in vitro fertilization. Other opportunities are available to use microorganisms as biofertilizers and biopesticides, and for bioremediation of the environment.

The Philippines is blessed with rich genetic resources waiting to be tapped for food, fiber, enzymes, and drugs. New beneficial genes are expected to be discovered in the highly diverse species of plants, animals, microorganisms, and marine organisms. The challenge is to save and use judiciously the rich biodiversity of the country. This biodiversity offers many opportunities in the search for novel genes and gene products. The Philippines has in place a law governing access to genetic resources by foreign and local bioprospectors. This law is designed to protect both the bioresource and the bioprospectors.

Because of the importance given to R&D in biotechnology under AFMA, introduction of foreign technologies, including genes that offer unique advantages, may have great potential for the country. For example, the sugar industry had been declining because of competition with high fructose syrup and other sugar substitutes. There are opportunities to use sugarcane, a highly efficient plant, to produce high-value products such as oral vaccines, biodegradable plastics, and other products. Collaboration between Philippine and overseas researchers is one opportunity that is now well in place. Many Philippine researchers actively collaborate with researchers from Australia, Canada, Japan, Republic of Korea, US, and countries of the European Union.

C. Constraints

Although the R&D opportunities are evident, there are some constraints that need to be addressed. Development of the local biotechnology industry has been hampered because of the inability of researchers to access state-of-the-art technologies. Researchers are therefore repeating work done elsewhere rather than being able to adopt current technologies.

Some nongovernment organizations and individuals in academe and government services do not support biotechnology. These groups are well organized and well funded, and are highly successful in promoting antibiotechnology sentiments in the country. They are also instrumental in persuading legislators to enact resolutions imposing moratoriums on research and commercialization of GIOs. Although they focus on geneti-

cally improved products produced and brought into the country by multinational companies, they also affect the R&D of local researchers.

The present set of biosafety guidelines is one of the strictest in the world. The guidelines were originally patterned after those first used in Australia, Japan, and US during the early 1980s. Since then, all these countries have relaxed most of their guidelines as a result of new technical data and familiarity in dealing with new products. The Philippines, however, has not relaxed its guidelines.

New genetically improved products cannot be commercialized in the country because the regulatory bodies cannot issue the required permits or licenses. The regulations allow only limited field trials of GIOs. The regulatory bodies lack the proper guidelines and institutional support to regulate the new products. This is a major constraint.

D. Conclusions

Researchers, policymakers, industry, and the international agricultural research centers (IARCs) must address the challenges, opportunities, and constraints that face biotechnology R&D. All countries share the same challenges, opportunities, and constraints although at different levels. They can be addressed by IARCs at the international level; by national R&D centers at a country level; and with harmonized activities at international, regional, and country levels.

For developing countries, the small farmers and fisherfolk should be the main beneficiaries of biotechnology R&D. Biotechnology will prosper only if the private sector actively participates in both the R&D and commercialization stages.

APPENDIX 9 AGRICULTURAL BIOTECHNOLOGY IN THAILAND¹⁰

A. Introduction

The agriculture sector in Thailand expanded by about 2.8 percent in 1998, although most of the economic sectors registered negative growth. Thailand's Ministry of Agriculture estimated that farmers would earn \$16.2 billion for the year, 74 percent of which would come from several major products including rice, shrimp, rubber, swine, sugarcane, and cassava.

The Government promotion to develop agribusiness since 1976 has greatly contributed to the expansion of agroprocessing. Combined export earnings from agriculture accounted for 23 percent of total earnings in 1998, according to the Department of Business Economics.

Recent exports have been hit by price competition from lower-wage Asian countries, demonstrating that Thailand cannot depend solely on its weaker currency to boost exports. To remain competitive, Thailand will have to focus more on the country's development, and be more innovative and creative in research and development (R&D). Increasing crop yield, protecting agricultural crops from diseases and pests, improving postharvest handling, and diversifying products are all priorities for Thailand. There is a need to increase productivity of Thai crops, while retaining their unique qualities (e.g., the fragrant Thai rice Khao Dawk Mali). Rice yield in Thailand averages only 2.4 tons/hectare (t/ha) compared with 6.3 t/ha in the United States, 6.0 t/ha in the People's Republic of China, 4.3 t/ha in Indonesia, and 3.6 t/ha in Viet Nam.

Thai sugarcane yields are only 48.8 t/ha compared with 93.8 t/ha in Brazil. The country's 46 sugar mills, meanwhile, have the capacity to process more than twice the amount of cane they now receive. Another problem with Thai cane is the sweetness. The international grading system has given a rating of 11 commercial cane sugar (ccs) for Thai sugar compared with 13 to 14 ccs for other countries. The Cane and Sugar Board's main activity at the moment is to develop better breeds with the goal of increasing the sweetness grade of Thai cane to 15 ccs within 5

¹⁰ See Tanticharoen (2000).

years. The new strain should also be disease-resistant, and tolerant of drought and saline soil.

A master plan for Thailand's agricultural development was approved by the Government in early 1998 to make exports more competitive. The objectives are supported by a master plan for industrial restructuring approved in April 1998. Thirteen industries will be promoted to make Thailand an important export center in Asia within 2 years. Among them are three industries using agricultural products (food and animal feed, rubber and rubber products, and wooden products including furniture). Key agricultural projects are:

- (i) Establishing integrated agricultural zones for exports.
- (ii) Conducting R&D to raise production and cut costs by using new technology with emphasis on biotechnology. Rice, live-stock, rubber, durian, longan, and orchids are priority commodities.
- (iii) Bringing product quality and processing up to international requirements. A center to control quality from the raw material stage to finished product will be established.
- (iv) Restructuring the Agriculture Ministry to modernize its management and services.
- (v) Encouraging farmers to use less chemical fertilizer while promoting natural alternatives and organic production.
- (vi) Improving management of land use and ownership, natural resources, irrigation, and coastal areas.
- (vii) Establishing weather warning systems in high-risk areas.
- (viii) Improving farm methods and technology.

The Agriculture Ministry outlined five strategic plans for 1999 with a budget of about \$1 billion:

- (i) Increasing competitiveness of farm products for export and import substitution (\$305 million), and promoting self-sufficient farm projects (\$24 million).
- (ii) Managing natural resources and the environment (\$372 million).
- (iii) Developing agricultural institutes to encourage community-based production (\$225 million).

- (iv) Implementing plans initiated by His Majesty the King (\$78 million).
- (v) Preparing for the twenty-first century (\$4 million).

Apart from the Government's annual budget, the Ministry has obtained \$600 million, mainly from the Asian Development Bank, to improve the agricultural economy through a series of short-and long-term programs.

B. National Center for Genetic Engineering and Biotechnology

The National Center for Genetic Engineering and Biotechnology (BIOTEC) was established under the Ministry for Science, Technology and Energy in 1983. When in 1991 Thailand established the National Science and Technology Development Agency, BIOTEC became one of the Agency's centers. It operates autonomously outside the normal framework of civil service and state enterprises. This enables it to operate more effectively to support and transfer technology for the development of industry, agriculture, natural resources, environment, and the socioeconomy.

BIOTEC policy provides the resources for the country to develop the critical mass of researchers necessary to achieve Thailand's national R&D requirements in biotechnology. This is achieved through in-country R&D, the facilitation of transfer of advanced technologies from overseas, human resource development at all levels, institution building, information services, and the development of public understanding of the benefits of biotechnology.

BIOTEC is both a granting and implementing agency. It allocates approximately 70 percent of its R&D budget to several universities and research institutes in Thailand, and 30 percent for in-house research projects. The facilities of national and specialized laboratories are made available for in-house research programs as well as for visiting researchers. The Science and Technology Park, which was completed in early 2001, houses BIOTEC's main laboratories.

Several research programs have been undertaken by a BIOTEC-appointed committee of recognized experts in the field. The major biotechnology programs and activities are described below.

1. Shrimp

Basic knowledge about the major cultivated shrimp species has lagged behind technical innovations that have led to successful intensification of culture, and to ever-increasing world production. Sustaining high production will require innovation to minimize adverse environmental impacts. Biotechnology will play a central role in helping to learn more about shrimp and thereby improve rearing practices. BIOTEC's support will focus on issues dealing with shrimp diseases and with improvement of the seed supply. The disease work has so far emphasized the characterization, diagnosis, and control of serious shrimp pathogens, particularly the viruses responsible for yellow head disease (YHD) and white spot syndrome (WSS). Luminescent bacterial infections have contributed to declining production to a lesser degree. These diseases have become progressively more serious threats to the industry as it has grown and intensified. Indeed, the work supported by BIOTEC on YHD and WSS viruses has been instrumental in substantially reducing losses in Thailand. The losses to YHD (probably exceeding \$40 million in 1995) and those to WSS (probably exceeding \$500 million in 1996) could have been much more serious without the basic knowledge and the DNA diagnostic probes made available to the industry by Thai researchers. Checking for subclinical WSS virus (WSSV) infections by polymerase chain reaction (PCR) has been a common practice to help farmers screen out WSSV +ve before stocking (Flegel 1997).

The Shrimp Biotechnology Service Laboratory was established at BIOTEC in 1999 to summarize the reference PCR methods for viral disease detection. Laboratory objectives are to serve as the reference laboratory for major shrimp pathogen diagnosis based on molecular techniques, to conduct research, and to provide assistance for molecular detection of various shrimp viruses.

It has been reported that WSSV can be vertically transmitted and become widespread among wild broodstock. In addition to the disease problem, a decline in the growth rate of shrimp produced from currently available wild broodstock has also been observed. Production of specific pathogen free animals and the development of specific pathogen resistant strains are now being used in the United States, Venezuela, and French Polynesia with *Penaeus stylirostris* and *P. vannamei*. This could be considered a breakthrough since production of *P. vannamei* more than doubled during 1992-94. Currently, the most important program involves the do-

mestication and genetic improvement of *P. monodon* stocks (Withyachumnarnkul et al. 1998). The project will lead to the development of specific pathogen resistant stocks and improved growth through selective breeding. BIOTEC is also supporting advanced studies on deoxyribonucleic acid (DNA) characterization and DNA tagging of the shrimp stocks. These studies are providing the tools that will be important for rapid genetic improvement strategies.

BIOTEC is dedicated to the principle that the players in the shrimp industry should take an active role in planning and financing R&D for their industry. BIOTEC actively promoted the formation in 1996 of an industry consortium, the Shrimp Culture Research and Development Company, dedicated to solving problems common to the shrimp aquaculture industry as a whole. This consortium serves the industry directly and also serves as a bridge to other public and private institutions involved in relevant research, not only in Thailand but throughout the world.

2. Cassava and Starch

About 70 percent of the 16 million tons (t) of cassava roots produced in 1998 was used in the production of pellets and chips; the remaining 30 percent was used mainly to produce flour and starch. A production shortage in 1997-98 prompted the Thailand Tapioca Development Institute (TTDI) and Kasetsart University to develop a new strain with a higher yield, Kasetsart 50. It has an average root yield of 26.4 t/ha and a starch content of 26.7 percent compared with 13.75 t/ha and 18 percent starch content for the best strain available until its release.

The tapioca starch industry is one of the largest in Thailand. In 1998, tapioca starch was worth about \$120 million. About 40 percent of starch was used domestically to produce modified starch, sweetener, and monosodium glutamate. Most of the remaining 60 percent was exported. Efficient production, low production costs, and the development of value-added products are vital to the starch industry and the farming sector (total of 1.3 million ha planted to cassava). The program on starch and cassava products was established to provide R&D support and funding. The program is funded jointly by BIOTEC and TTDI to carry out R&D in three core activities: processing, diversification, and characterization.

a. Processing Efficiency

The short-term project aims to improve the processing efficiency of starch production, in particular to minimize water and energy consumption. Wastewater discharge varies from 13 to 50 cubic meters/ton (m^3/t) of starch produced, with an average of 20 m^3 . A benchmark on water use is a priority for the Thai starch industry.

Biotechnology can play an important role in waste utilization. Solid waste (after starch extraction) still contains 50 percent starch (dry weight) and has been used as animal feed. Tapioca, however, is not suitable for the production of feed requiring high protein content. Attempts have been made for protein enrichment using various microorganisms such as *Aspergillus* and *Rhizopus*. Nevertheless, the economic feasibility is still in doubt and further technological development is needed. In contrast, turning wastewater into energy through high-rate anaerobic digestion is promising. Though the technology is proven, an adaptation to such high-strength wastewater and low buffering capacity is required to ensure stability of the system. In comparison with the upflow anaerobic sludge bed reactor, the fixed bed is easier to control and operate. R&D, however, is focused on increasing loading efficiency. Based on calculations, methane generated from anaerobic treatment of starch wastewater from 60 factories would be approximately 630 million m^3 annually. This could be substituted for fuel oil used in drying, saving energy costs of about \$4 million annually. There is also the environmental cost of large land areas required for conventional evaporation pond systems. In addition to native starch, production of modified starch is increasing, leaving an excessive amount of sulfate in wastewater. This may interfere with the anaerobic digestion intended for energy production. A number of papers have been published recently on the interactions between the sulfate reducing bacteria and the methanogenic bacteria. Molecular diagnosis has been developed and applied for the mixed culture system. A better understanding of these anaerobic microbes could lead to the biological removal of sulfate, which is the main problem of various industries.

b. Product Diversification

Product diversification is part of the second core research activity. The European Union has set a quota for imported tapioca pellets. As a result, production of biodegradable plastic from cassava starch is being

investigated. Increasing use of cassava as a raw material for fermentation products, such as amino acids and organic acids, must proceed, expanding the development of value-added products. To reduce costs of production, however, research is oriented toward the production of good quality cassava chips as a starting material to replace the starch.

c. Starch Structure and Properties

Basic research on cassava starch structure and properties will add to our knowledge and help increase the use of cassava starch. The Cassava and Starch Technology Unit, a specialized BIOTEC laboratory established in 1995 at Kasetsart University, has been studying the physicochemical properties of cassava. The unit is well equipped, and provides regular service and training on instrumental analysis of starch properties to the private sector and government agencies.

3. Rice

Rice yields in Thailand are low. One of the major constraints is blast disease, especially in high-quality rice cultivars such as the aromatic Khao Dawk Mali. In northern Thailand, about 200,000 ha of rice were affected by blast in 1993, causing serious economic loss and resulting in government intervention of about \$10 million to assist disease-struck farmers. Another \$1.2 million was spent on fungicides (Disthaporn 1994). Breeding higher resistance levels to blast in Thai rice has been attempted. Limiting factors, however, are lack of insight and information on resistance genes, and the complex structure of the pathogen populations. Genetic analysis provides an efficient tool to identify useful resistance genes in the host while analyzing the race composition of the pathogen population. Recent research applying molecular genetic methods (DNA fingerprinting of a blast isolate collection at Ubon Ratchathani Rice Research Station, and mapping of host resistance genes by the DNA Fingerprinting Unit at Kamphaengsaen campus of Kasetsart University) are providing baseline data on the interaction between rice and blast. The project is working on three closely related areas as follows:

- (i) Establishment of a suitable differential cultivar series; identification of resistance genes conferring complete and partial resistance to blast disease in rice.

- (ii) Pathotype and molecular genetic characterization of the blast pathogen population in Thailand. So far, more than 500 monospore isolates have been deposited with the BIOTEC specialized culture collection.
- (iii) The special case of fertile isolates; the potential of using Thai isolates of *Magnaporthe grisea* for the development of a molecular diagnostic tool for pathogen race analysis. The degree of fertility can be assessed from the timing and number of perithecia that develop. BIOTEC has the capacity to test the mating type of about 80 isolates per month.

This project is a nationwide, network-type collaboration combining molecular genetics and classical approaches to help scientists breed rice cultivars with improved blast resistance.

BIOTEC provided \$1.5 million in 1999 to fund the Rice Genome Project Thailand. On behalf of Thailand, BIOTEC has joined the International Collaboration for Sequencing the Rice Genome (ICSRG) by sequencing 1 megabyte annually of chromosome 9 for the next 5 years. BIOTEC is expected to provide about \$3.7 million to cover this work. Chromosome 9 was selected based on previous extensive work on the fine genetic and physical maps surrounding the submergence tolerance quantitative trait loci (QTL), the prospect of gene richness, and the small chromosome size. Joining ICSRG will allow Thai scientists to directly access the rest of the genome sequence made available by the other collaborating members. Gene discovery from wild rice germplasm will be undertaken in parallel to efficiently use the genome sequence data. The project will bring Thailand into the international scientific arena, incorporate state-of-the-art technology, and improve Thailand's competitive edge in the international rice market.

4. Dairy

In 1997, Thai milk consumption was 12 liters/person/year. Milk production is still insufficient to meet local demand, and Thailand has to import more than 50 percent (worth \$305 million) of the dairy products consumed in the country. An additional 130,000 cows are needed to meet the national demand.

Reproductive efficiency is a primary determinant of dairy herd production profitability. Milk yield (10 kilograms/day) is still far below the

average (30 kilograms/day) of most developing countries. It is therefore important to promote an increase in dairy production through science and technology. The major programs are breeding and feeding. The lack of proper management is another major contributing factor to an underproductive dairy industry.

Traditional breeding practices in Thailand have been too slow to meet national requirements. And importing pregnant heifers or young quality-bred calves from abroad is too costly. Cutting-edge technologies such as embryo transfer, in vitro fertilization, embryo sexing, and semen sexing have been studied by Thai scientists for more than 10 years. Nevertheless, the technologies have not yet been adopted. Technology transfer and training of Thai researchers at the leading laboratories or companies are now under discussion. The goal is to increase production of high-quality heifer calves at the lowest cost.

5. Genetic Engineering

By the mid 1970s, with biotechnology centered on genetic engineering and molecular biology, Thailand was ready to adopt the new tools and apply them to various practical problems, first in the biomedical field and later in agriculture and other areas. A few specific examples will be given here to highlight the application of molecular biology and genetic engineering to agricultural development. Efforts in agricultural biotechnology and genetic engineering have been focused on three main areas: plant transformation, DNA fingerprinting, and molecular diagnosis of plant and animal diseases. The first area should lead to the production of transgenic plants with superior properties including resistance to diseases and insect pests, and tolerance for abiotic stresses.

a. Plant Transformation

The Plant Genetic Engineering Unit, the specialized laboratory of BIOTEC at Kasetsart University, Kamphaengsaen, was established in 1985 to work on plant biotechnology and genetic engineering. A transgenic tomato plant carrying the coat protein gene of tomato yellow leaf curl virus was first developed to control this serious virus disease of tomato (Attathom et al. 1990). The same approach was taken to develop transgenic papaya resistant to papaya ringspot virus and pepper resistant to chili vein-banding mottle virus (Chaopongpang et al. 1996; Phaosang et al.

1996). Sri Somrong 60, a Thai cotton variety, was successfully transformed with cryIA[b] gene expressing a toxin from *Bacillus thuringiensis* (Bt). Development of transgenic rice varieties has been supported by the Rice Biotechnology Program launched by BIOTEC and the Rockefeller Foundation. An example is the transformation of Khaw Dawk Mali 105, an aromatic Thai rice with delta 1 pyrroline-5-carboxylate synthetase for salinity and drought tolerance. Most transgenic plants are now being tested in the greenhouse in accordance with the Biosafety Guidelines (Attathom and Sriwatanapongse 1994, Attathom et al. 1996). Field testing of transgenic plants developed in Thailand will begin in 2000.

b. DNA Fingerprinting

Using DNA fingerprinting and PCR, scientists can identify organisms and genes, and make genetic maps. DNA probes and specific gene sequences have made possible molecular methods for diagnosis of plant and animal diseases. Molecular mapping of genes in rice involving submergence tolerance, rice blast, aroma, cooking quality, and fertility restoration were accomplished using three mapping populations. A backcross breeding program for the improvement of Jasmin rice was initiated. In the first stage, resistance to bacterial leaf blight, submergence tolerance, resistance to brown planthopper and gall midge, and photoperiod insensitivity were main areas of focus. Restriction fragment length polymorphism markers were an important limiting factor for high throughput and cost effectiveness. The PCR marker for *Xa21* gene is the most reliable for marker-assisted backcrossing in rice.

c. Molecular Diagnosis

Tomato production in the tropics and subtropics faces serious constraints due to bacterial wilt (BW), a disease caused by the bacterial pathogen recently reclassified as *Ralstonia solanacearum* (previously *Pseudomonas solanacearum*). In Thailand, an endemic outbreak of BW in tomato, potato, pepper, ginger, and peanut occurs each year, causing a yield loss of approximately 50-90 percent depending on growing conditions. BW-resistant varieties cannot easily be developed due to the nature of the quantitatively inherited resistance that involves several genes. Marker-assisted selection (a breeding method of selecting individuals based on markers linked to target genes), in addition to phenotypic measurement,

is essential and useful only for enhanced resistance to diseases. At this time, three putative QTLs corresponding to BW resistance have been found using amplified fragment length polymorphism markers. Once markers closely linked to BW-related QTLs are well established, they can be used for marker-assisted breeding for enhanced resistance to BW in tomato. A tomato consortium has been set up to extend public-private collaboration.

BIOTEC has set up the DNA Fingerprinting Service Unit at Kasetsart University. The unit has provided services to public and private concerns for more than 2 years. The main services are DNA fingerprinting and DNA diagnosis.

6. Biocontrol

In 1996, Thailand imported 38,000 t of chemicals, mainly insecticides and herbicides. The global trend of going organic is an opportunity for Thai farmers to supply fresh organic produce, especially fruit and vegetables, to the world. Over the past decade, developmental work on biocontrol in Thailand has continued to receive active support from BIOTEC and the Thailand Research Fund. Two companies are now commercially producing *Trichoderma* to control *Sclerotium rolfsii*, and *Chaetomium* to control soil fungi such as *Phytophthora* (Yuthavong 1999). BIOTEC and the Department of Agriculture have set up a pilot-scale production facility to produce nuclear polyhedrosis virus (NPV), Bt, and *Bacillus sphaericus*. NPV is widely used to control *Spodoptera* moth in grapes. Bt produced locally has gained popularity over the last few years. The capacities of pilot plants at Mahidol University and King Mongkut's University of Technology, Thonburi, are fully taken up with Bt production. Commercial production may begin soon. A project at Mahidol University to transfer the chitinase gene into *Bacillus thuringiensis* subsp. *israelensis* has received support from BIOTEC.

C. Trade in Agricultural Products

Although Thailand is a leading exporter of food products, it also imports food commodities that are not available or that cannot be adequately supplied through local production. Among Thailand's top 10 food imports in 1998 were fresh and frozen tuna for canning, and vegetable

materials for animal feed preparation. Maize, soybean meal, and fishmeal are key ingredients for feed industries. Maize production for the 1998-99 crop year was approximately 4.9 million t, whereas local demand, mainly from animal feed factories was about 3.8 million t. With adequate supplies, no maize imports were permitted in 1999 beyond the 53,250 t that Thailand had committed to allow under the World Trade Organization agreement. In contrast, soybean output was about 375,000 t in 1999, about 800,000 t below the 2000 expected consumption of 1.17 million t. In addition, about 680,000 t of soybean meal were produced in 1999—100,000 t from local soybeans and the rest imported.

Transgenic varieties account for over 50 percent of world soybean production, mainly from North America, despite regulations governing genetically improved organisms (GIOs) becoming more and more restrictive. In mid 1999, for example, the European Agriculture Commissioners made a political agreement to ban the use of GIOs in animal feed. Thailand should be able to deal with potential problems. DNA analysis has been used to confirm the origin of raw materials used in food processing to comply with trade agreements. The DNA Fingerprinting Unit will check the species identification of tuna already canned. This addresses the conflict between global free trade and environmental protection. The United States Department of Commerce proposes to prohibit importing Atlantic-caught bluefin tuna harvested by countries using methods inconsistent with the International Convention for the Conservation of Atlantic Tunas.

D. Biosafety

Biosafety issues are only now being debated in Thailand and the underlying concepts are unfamiliar even to academics and certain regulatory agencies. The National Biosafety Committee (NBC) was established in January 1993 under BIOTEC. NBC has introduced two biosafety guidelines; one for laboratory work, and the other for field work and the release of GIOs into the environment. The establishment of institutional biosafety committees at various public institutes and private companies was also strongly recommended. In many cases these recommendations have been implemented.

The importation of prohibited materials under Plant Quarantine Law B.E. 2507, implemented by the Department of Agriculture, controls to

a certain degree the use of GJOs. Permission from the Ministry of Agriculture is required to perform field testing of transgenic plants brought into Thailand. The following GJOs have received permission and undergone field testing: the Flavr Savr tomato produced by Calgene for the production of seeds (1994); screenhouse testing of Monsanto Bt cotton (1996); and screenhouse testing of Bt maize by Novartis at its experiment station (1997).

Thailand is rich in biodiversity, and several genes for resistance to biotic and abiotic stresses embedded in wild plants and other bioresources need to be identified and incorporated into cultivars. This illustrates the potential benefits of biotechnology and genetic engineering. In the 1980s, when genetic engineering and biotechnology first made their impact felt, genetic engineering capability was present in only two or three institutions in Thailand (Yuthavong 1987). Ten institutions now have genetic engineering capability. Nevertheless, the most important challenge for the future of GJOs is not technical in nature, but in the attitudes of the public toward the technology. These issues need to be studied and debated among scientists, the public, and policymakers, and an optimal policy developed. BIOTEC realizes that genetic engineering depends critically on public support. Therefore it has emphasized public education, with information programs on biotechnology produced for the public and industry.

APPENDIX 10 AGRICULTURAL BIOTECHNOLOGY IN VIET NAM¹¹

During 1990-1995, production of food crops, including rice, maize, sweetpotato, cassava, and potato, achieved an average annual growth rate of 4.3 percent in Viet Nam. This growth rate far exceeded the population growth rate of 2.2 percent and led to a significant increase in per capita food availability as well as surplus for export.

The growth that has taken place during those years was largely due to applications of technology. Among applied technologies, biotechnology has made a significant contribution and is critical for increasing crop production to satisfy increasing domestic needs, to meet new export market demands, and to conserve natural resources by developing improved and more sustainable agricultural systems.

The role of biotechnology in agriculture development has been led by Government, policymakers, and scientists. A national Council of Biotechnology was established under the chairmanship of the head of the Department of Fundamental Sciences of the State Committee for Sciences in 1991. A national program on agrobiotechnology was established to (i) improve and produce biomaterials for agriculture, (ii) improve quality and productivity of crops and livestock husbandry, and (iii) conserve biodiversity and protect the environment. Genetic engineering, plant cell technology, and recombinant DNA techniques are considered prerequisite technologies for agricultural productivity.

A. Policy and Institutions

Viet Nam has assigned the highest priority to agrobiotechnology. Government policy views it as essential and increasingly important to achieve national goals and objectives for food, feed, and fiber production. Accordingly, substantial resources have been devoted to build capacity in several national institutions. The main institute for biotechnological research is the Institute of Biotechnology at the National Center of Natural Science and Technology. There are also the research institutions belonging to the

¹¹ See Truong-van Nguyen (2000).

Ministry of Agriculture and Rural Development: the Institute of Agricultural Genetics and Institute of Agricultural Sciences. In universities, there are new courses specializing in genetic engineering and biotechnology. In addition, there are genetic engineering research centers being established within the universities.

B. Investment

The international benefits of biotechnology to agriculture production have drawn attention from the Government, policymakers, and scientists to the biotechnology research and development (R&D) program. Financial support has come from national and provincial sources. Several plant tissue culture laboratories have been set up in many provinces to meet the requirement for quality, quantity, and productivity of vegetative crops.

Nevertheless, capital investment of Government for biotechnological research and development is low compared with other countries in the region. There is little foreign investment for research. At present, only about 1 percent of the national budget is spent on all agricultural research. Also, there has not been adequate international support in this regard, except for purchases of equipment on a small-scale.

C. Human Resources

Human resources are also an important factor for facilitating technology transfer and adaptation. The Government is taking the necessary steps to ensure that the target will be met, including a significant investment in human capital that will build a sustainable capacity in biotechnology in Viet Nam. Local universities have opened biotechnology courses for biology and agriculture students. At present, there are not enough capable scientists with adequate exposure to advanced biotechnology, especially in genetic engineering. There are a little over 200 scientists involved in biotechnology R&D. Few opportunities exist for interaction with national and international research scientists and organizations.

D. Research and Development Programs

Vietnamese agrobiotechnology is largely at the stage of improving technology imported from industrial countries. The conventional technologies such as in vitro micropropagation, virus elimination, somaclonal variation, anther culture, and haploid lines effectively improved crop productivity over the past decade. Production of diagnostics and vaccines to detect and prevent livestock diseases and pathogens, and reproduction of domestic animals (embryo transfer) have also been applied for improved animal husbandry.

Gene transfer to breed disease- and pest-resistant crop varieties, and plants tolerant of adverse environments is being pursued. Transgenic crops for the potential control of viral and fungal diseases are at the laboratory testing levels. Various genes have been cloned or imported from other countries for traits for resistance to insects and to bacterial and fungal diseases; tolerance for salinity, drought, and cold; and increased shelf life. These are being introduced into Vietnamese crop varieties for evaluation.

New molecular techniques are being used to characterize biodiversity in rice. Molecular-marker assisted selection is being used in rice breeding. Other new techniques used for rice improvement include anther culture, somaclonal variation, and genetic transformation.

The current priorities in crops and traits for crop biotechnology in Viet Nam are shown in Table A10.1.

Table A10.1: Crop Biotechnology Priorities of Viet Nam

Crop	Biotechnology Technique
Rice	Hybridization, gene transformation
Maize	Diagnosis
Potato	In vitro tuberization
Sweetpotato	Bt transgenic plants with insect resistance
Cassava	Propagation
Soybean	Abiotic stress tolerance, Rhizobia strains for Mekong Delta soil
Sugarcane	Germplasm, propagation, rust and stem borer resistance
Fruits and Vegetables	PRSV resistance (papaya)
Cotton	Transgenic Bt plants

Bt = *bacillus thuringiensis*, PRSV = papaya ringspot virus.

The priority for crop biotechnology focuses on genetic modification for improved crops such as rice, maize, roots and tubers, soybean, sugarcane, cotton, and fruits and vegetables to achieve food security in the future.

E. Future Strategy

Viet Nam plans to (i) commit to sustainable agriculture development and protecting the environment; (ii) improve international networking with applied research institutes and encourage foreign investment in agrobiotechnology to facilitate technology transfer; (iii) improve research facilities, particularly those of applied research that aim to adapt international technology to local needs; and (iv) rationalize the number of research institutes, improve research coordination, and increase training staff.

With such strategies, the Vietnamese government plans to invest in its national research institutes, laboratories, and training centers at the universities, including increased investment in information and library facilities.

Even with the limitation of funding, facilities, and experienced scientists, Viet Nam has recognized the important role of biotechnology in the development of agriculture. It has begun increased investment and encouraged capable scientists to become actively involved in biotechnology R&D.

APPENDIX 11 BIOTECHNOLOGY ACTIVITIES OF THE CGIAR CENTERS RELEVANT IN ASIA

Table A11.1: CGIAR Centers with Crop Improvement Activities in Asia

Center	Full Name	Year Founded	Host Country	Mandate Crops
CIAT	Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)	1967	Colombia	Cassava
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo (International Maize and Wheat Improvement Center)	1966	Mexico	Maize, Wheat
CIP	Centro Internacional de la Papa (International Potato Center)	1970	Peru	Potato, Sweetpotato
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics	1972	India	Sorghum, Millet, Groundnut, Chickpea, Pigeonpea
IPGRI	International Plant Genetic Resource Institute	1974	Italy	Genetic Resources, Cocoa, Coconut/Musa species
IRRI	International Rice Research Institute	1960	Philippines	Rice

CGIAR = Consultative Group on International Agricultural Research, CIAT = Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture), CIMMYT = Centro Internacional de Mejoramiento de Maiz y Trigo (International Maize and Wheat Improvement Center), CIP = Centro de la Papa (International Potato Center), ICRISAT = International Crops Research Institute for the Semi-Arid Tropics, IPGRI = International Plant Genetic Resources Institute, IRRI = International Rice Research Institute.

Notes:

- (i) The CGIAR, established in 1971, is an informal association of 58 public and private sector members that supports a network of 16 international agricultural research centers.
- (ii) The CGIAR's mission is to contribute to food security and poverty eradication in developing countries through research, partnership, capacity building, and policy support. The CGIAR promotes sustainable development based on the environmentally sound management of natural resources.
- (iii) The CGIAR strives to make developing country agriculture more productive through genetic improvements in plants, livestock, fish, and trees. CGIAR centers conduct research programs in collaboration with a full range of partners in an emerging global agricultural research system. Food productivity in developing countries has increased through the application of research-based technologies. Experience shows that agriculture, including forestry and fisheries, is a powerful engine for development.

Source: CGIAR (2000).

Table A11.2: Biotechnology Methods Used and Developed in the CGIAR Centers

Crop	Center	Research and Applications
Maize	CIMMYT	<ul style="list-style-type: none"> • Markers (SSR) for diversity studies and IPR purposes, for opaque 2 (improved nutritional quality); single gene markers available for seed color and certain level of herbicide tolerance; markers especially with nonradioactive detection: RFLPs, RAPDs, SSRs, AFLPs. • MAS on experimental bases (insect resistance, drought tolerance, <i>Fusarium</i> ear rot, maize streak virus, <i>Striga</i>). • QTLs identified for low soil pH and aluminum toxicity tolerance, stem borer, fall armyworm, <i>Fusarium moniliforme</i>, downy mildew, and <i>Striga</i> resistance; potential application for maize streak virus. • Linkage maps. • Protocol for maize Bt and herbicide resistance. • DNA chip and microarray technologies.
Rice	IRRI	<ul style="list-style-type: none"> • Anther culture for breeding and mapping; embryo rescue; in vitro pollination, ovary culture; regeneration for transformation. • Molecular markers for germplasm characterization; FISH; RAPDs, STS markers. • Markers (isozymes, RFLPs, AFLPs, STS) for development of genetic stocks; markers available for wide-crossability genes and for quality; MAS kits for two gall midge resistance genes. • Alien genes mapped (e.g., <i>Xa21</i>); candidate genes. • Genetic map for interspecific population; molecular maps for salinity tolerance, phosphorus deficiency tolerance, submergence tolerance, elongating ability; cytogenic stocks for mapping; mapping populations shared with NARSS. • Identified favorable wild species' QTLs; identification and mapping of QTLs for orthologous loci governing agronomic traits. • Transformation with <i>Agrobacterium</i> and biolistic methods; transformation for Bt, resistance to bacterial blight. • Novel genes, constructs and promoters (apomixis, methylation-resistant constitutive expression). • Transgenic seeds transferred to NARSS. • <i>Knockout</i> populations; near isogenic lines, recombinant inbred lines; cDNA libraries; DH populations (isogenic lines and pyramids); <i>indica</i> BAC library.
Spring Bread Wheat	CIMMYT	<ul style="list-style-type: none"> • DH (maize system) for breeding, DHs being produced from key crosses; embryo culture for transformation. • Molecular characterization (limited by cost).

Table A11.2: Biotechnology Methods Used and Developed in the CGIAR Centers (cont'd.)

Crop	Center	Research and Applications
		<ul style="list-style-type: none"> • Markers used (RFLPs, RAPDs, SSRs, AFLPs - especially with nonradioactive detection); MAS (SSR) used for BYDV; MAS for enhancing nonhomologous recombination (<i>Ph1</i> gene). • Finalizing marker for high protein gene and for CCN; sought <i>Vrn/Ppd</i> development genes; preliminary markers for resistance genes (leaf and stripe rust, <i>Fusarium</i> head scab, karnal bunt). • Linkage maps. • Transformation protocol close to routine; transgenic wheat containing fungal resistance, Basta herbicide resistance, resistance genes (chitinase, glucanase, ribosome-inactivating protein, thaumatin-like proteins). • ESTs for wheat.
Durum Wheat	CIMMYT	<ul style="list-style-type: none"> • Testing DH system. • Initiating MAS, QTL. • Initiating transformation.
Sorghum	ICRISAT	<ul style="list-style-type: none"> • Identification of molecular markers for <i>Striga</i> resistance. • Identification of QTLs for mildew resistance.
Pearl Millet	ICRISAT	<ul style="list-style-type: none"> • Markers for downy mildew resistance; genetic maps; primers; work on markers for resistance gene pyramiding and drought tolerance; SSR markers being developed for pearl millet. • Studies on QTLs for downy mildew, heat and drought tolerance, grain and stover yield components, ruminant nutritional quality in residues.
Cassava	CIAT	<ul style="list-style-type: none"> • In vitro culture for multiplication; cryopreservation. • Genetic map developed, saturated map under way. • Adjusting protocol for transformation: herbicide resistance, Bt, novel starch forms. • BAC library.
Potato	CIP	<ul style="list-style-type: none"> • Hybrid clones; dihaploids. • Molecular characterization of pathogen populations. • Mapping populations produced; candidate genes for potato late blight; probes and primers corresponding to plant defense genes. • Search for QTLs for resistance to potato late blight; association of several mapped QTLs with known defense genes. • Transformation efficiency needs improvement; work on selectable marker systems.

Table A11.2: Biotechnology Methods Used and Developed in the CGIAR Centers (cont'd.)

Crop	Center	Research and Applications
Sweetpotato	CIP	<ul style="list-style-type: none"> Transformation for potato tuber moth resistance; work on bacterial wilt resistance. <i>Rxadg</i> and <i>Rxaci</i> genes cloned. BAC library containing Rysto gene.
		<ul style="list-style-type: none"> Meristem culture; micropropagation. Markers (RAPD, AFLP, SSR); fingerprinting. Genetic linkage map produced. Tagging single/oligogenes; tagging QTLs. Success in transformation with weevil resistance (soybean proteinase inhibitor); safety testing needed; search for appropriate Bt gene.
Coconut	IPGRI COGENT	<ul style="list-style-type: none"> Micropropagation. Molecular markers for diversity studies and characterization; microsatellite primers. Initial work on genome mapping.
Chickpea	ICRISAT	<ul style="list-style-type: none"> Embryo culture. Molecular markers for diversity analysis. Preliminary, reasonably-saturated, marker-based chickpea linkage map developed. Transformation protocol available.
Groundnut	ICRISAT	<ul style="list-style-type: none"> Tissue culture; embryo rescue. RFLP, some SSR markers, and a skeleton molecular map available; disease-resistant genes, and markers (RAPD) linked with resistance identified; SSR and AFLP markers specific to groundnut identified. Transformation employed for Indian peanut clump virus and groundnut rosette virus; materials evaluated in containment facilities.
Pigeonpea	ICRISAT	<ul style="list-style-type: none"> Work elsewhere on markers and linkage maps. Transformation protocol, particularly regeneration under investigation.

AFLP = amplified fragment length polymorphism, Bt = *bacillus thuringiensis*, cDNA = complementary DNA, CGIAR = Consultative Group on International Agricultural Research, CIAT = Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture), CIMMYT = Centro Internacional de Mejoramiento de Maiz y Trigo (International Maize and Wheat Improvement Center), CIP = Centro de la Papa (International Potato Center), COGENT = Coconut Genetic Network, DNA = deoxyribonucleic acid, ICRISAT = International Crops Research Institute for the Semi-Arid Tropics, IPGRI = International Plant Genetic Resources Institute, IPR = intellectual property right, IRRI = International Rice Research Institute, MAS = marker-assisted selection, NARS = national agricultural research system, QTL = quantitative trait loci, RAPD = randomly amplified polymorphic DNA, RFLP = restriction fragment length polymorphism, SSR = simple sequence repeats, STS = sequence-tagged sites.

Source: Consultants' assessment.

Table A11.3: Resource Commitments for Plant Breeding and Biotechnology in 1999 by Selected CGIAR Centers
(\$'000)

Resource Commitments	CIAT	CIMMYT	CIP	ICRISAT	IPGRI	IRRI
Biotechnology ^a	1,324	3,280	1,469	698	853 ^b	
Crop Improvement Professional Staff	8,270	10,500	5,450	5,000	2,600 ^c	11,440
Years in Biotechnology Professional Staff	12	na	14	8	2	38
Years in Crop Improvement	14	na	46	24	2	63

CGIAR = Consultative Group on International Agricultural Research, CIAT = Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture), CIMMYT = Centro Internacional de Mejoramiento de Maiz y Trigo (International Maize and Wheat Improvement Center), CIP = Centro Internacional de la Papa (International Potato Center), ICRISAT = International Crops Research Institute for the Semi-Arid Tropics, IPGRI = International Plant Genetic Resources Institute, IRRI = International Rice Research Institute, na = not available.

^a Including salaries and running costs, excluding overhead and capital costs for research, development and applications.

^b Musa and coconut only.

^c Including all IPGRI activities for crop improvement.

Source: Centre Medium-Term Plans 2001-2003: 1999 actuals (including overhead) for crop improvement output.

**Table A11.4: Resource Commitments by Biotechnology Activity in 1999
by CGIAR Center**
(\$'000)

Biotechnology Activity	CIAT	CIMMYT	CIP	ICRISAT	IPGRI^a	IRRI
1. Tissue Culture (somaclonal variation, embryo rescue, haploids, micropropagation)	125	164	133	94	—	118
2. Tissue Culture (protoplast culture and fusion)	—	—	—	—	469	56
3. DNA Fingerprinting	163	492	—	27	—	117
4. Marker Identification and MAS	330	820	449	193	55	791
5. Gene Sequencing	133	492	124	—	—	304
6. Genetic Engineering	225	820	703	95	329	504
7. Diagnostics	205	164	—	201	—	196
8. Networks and Training	143	328	60	—	—	354
9. Others	—	—	—	88	—	190
Total Center	1,324	3,280	1,469	698	853	2,630

— = not available, CGIAR = Consultative Group on International Agricultural Research, CIAT = Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture, CIP = Centro Internacional de la Papa (International Potato Center), CIMMYT = Centro Internacional de Mejoramiento de Maiz y Trigo (International Maize and Wheat Improvement Center), DNA = deoxyribonucleic acid ICRISAT = International Crops Research Institute for the Semi-Arid Tropics, IPGRI = International Plant Genetic Resource Institute, IRRI = International Rice Research Institute, MAS = marker-assisted selection.

^a Musa and coconut only.

Source: Centre Medium-Term Plans 2001-2003.

Table A11.5: Summary of Breeding and Biotechnology Capacities of Different NARS Types

	Type 1 NARS— Very Strong	Type 2 NARS— Medium Strong	Type 3 NARS— Fragile or Weak
Market size	Large to very large	Medium to large	Small to medium
Plant Breeding	Strong national commodity programs with comprehensive breeding programs, including some prebreeding.	National commodity programs that are generally strong in applied breeding.	Usually small and fragile programs with success dependent on one or two persons. Usually conduct own crosses; value added of local adaptation often low due to small market size.
Use of IARC Materials	Used as parents to obtain specific traits for breeding and prebreeding, and sometimes released directly. Also use early generation materials.	Very important as parents, and also as direct releases.	Mostly direct releases after local screening and testing.
Basic and Strategic Research	Often considerable capacity that can match that in IARCs.	May have capacity in specific areas.	No capacity.
Private Sector	Private sector very active for hybrid crops and increasingly for nonhybrids.	Private sector activity increasing and usually involved in hybrid crops.	Little private sector activity for food crops.
Biotechnology Research	Capacity in molecular biology as great or greater than most IARCs. Marker-assisted selection being incorporated into breeding programs. Considerable research on transgenics.	Usually developing capacity in molecular biology, but with considerable support from donors and IARCs.	Very little capacity in molecular biology although many have tissue culture capacity.
Regulatory Framework for Biosafety and IPR	Framework in place although capacity to implement is modest and untried.	Most countries have or soon will have framework, but weak capacity to implement.	Most countries do not have regulatory framework.

IARC = international agricultural research center, IPR = intellectual property rights, NARS = national agricultural research system.

Source: CGIAR (2000).

APPENDIX 12 INTELLECTUAL PROPERTY RIGHTS

A. Introduction

Intellectual property rights (IPR) can be defined as a set of laws devised to protect or reward inventors or creators of new knowledge. Because knowledge, unlike consumable goods, can be shared by any number of persons without being diminished, creators are dependent on legal protection to prevent direct copying or use of their product or process without being compensated. IPRs are therefore intended to confer exclusive rights to inventors or discoverers for a fixed period.

The concept of protecting intellectual property is not new. In fact, according to Greek records, monopoly rights were granted to traders or investors as early as 200 B.C. Since the Industrial Revolution, patent protection has expanded rapidly. Germany, for example, passed a modern patent law in 1877. By 1988, some 115 countries allowed patent protection in one form or another. Of those countries, more than 50 excluded biological inventions—plants and animal varieties—from protection.

As agricultural research and modern plant breeding developed, plant breeders also began to seek intellectual property ownership and protection over their products. They argued that their contribution to society should be recognized in the same way as the contribution of industrial inventors.

That led in the 1920s to the introduction of legislation in some European countries, and in the United States (US) in the 1930s, to protect new plant varieties. The United States Plant Patent Act of 1930 allowed patent protection only for asexually reproduced plants, excluding tubers. Sexually-reproduced plant life was excluded due to its particularity of evolving and modifying over generations, making it difficult to determine what was originally patented.

The first international effort toward extending and harmonizing plant breeders' rights (PBRs) took place at the 1956 congress of the International Association of Plant Breeders for the Protection of Plant Varieties in Austria. That led, in 1961, to the first International Convention for the Protection of New Plant Varieties, known by its French acronym, *Union pour la protection des obtentions Végétales* (UPOV).

Following the Paris Convention, plant breeders began to press for the equivalent of patents in plant protection. Intellectual property protection (IPP) related to plant genetic resources and plant varieties developed separately, due in part to the complexity and difficulty of protecting living matter. While the forms of IPRs related to industrial and agricultural technology evolved separately, there has been a gradual but marked strengthening of IPP in all fields of innovation over the years. This has occurred partly as a result of growing concern over losses to patent-holders incurred by the infringement of IPRs, particularly in the form of copyright and brand names.

With the advent of biotechnology, the ways in which industrial and biological innovations are protected are converging, at least in member countries of the Organisation for Economic Cooperation and Development (OECD). An important step in this direction was taken in 1980 by the US Supreme Court in *Diamond v. Chakrabarty*. That landmark decision allowed the patenting of a genetically modified organism for the first time. The first patent application for a transgenic plant was filed in 1983. The first industrial patent for a plant variety was awarded in the US in 1985. And the first patent for a transgenic plant in Europe was awarded in 1988. During the 1980s, the number of patent applications in plant biotechnology rose to some 250 per year. The 1991 revision of the UPOV Convention brought PBRs further into line with patents.

United States insistence that the absence of comprehensive patent and other intellectual property laws constitutes nontariff barriers to trade, led to the inclusion of "trade-related intellectual property" in the Uruguay Round of multilateral trade negotiations. Efforts to strengthen and extend IPRs led to the Agreement on Trade-Related Aspects of IPR. This meant that the locus of discussion and negotiations on IPRs shifted from the technically-based work of the World Intellectual Property Organization, a United Nations body, to the newly created World Trade Organization.

B. Forms and Scope of IPRs Relevant to Technology Transfer in Agriculture

The principal forms of IPRs and the differences and similarities between these forms are indicated below:

1. Patents

The most common form of IPR is the patent; any invention not expressly prohibited can be patented. Discoveries, scientific theories, and mathematical formulas are excluded from patenting as are items considered offensive to public morals. Patents may be granted for different kinds and levels of invention including: products products-by-process, uses, and processes. Patents therefore apply to an ever-widening range of product and process inventions including, in a growing number of countries, selected living matter such as DNA sequences, genes, microorganisms, plant parts, and plant and animal varieties. Many developing countries, as well as a number of OECD member countries, exclude pharmaceuticals and agriculturally related products (including plant and animal varieties) from patenting.

The granting of a patent confers monopoly rights on the holder, or inventor, over the use and benefit of an invention for a fixed period. The period differs from country to country, but usually varies between 14 and 20 years. During that time the inventor has the right to prevent others from producing, using, selling, offering for sale, or importing the invention, or to require a fee (licensing) in return for its use.

The granting of a patent is subject to three conditions: (i) usefulness or industrial application; (ii) newness or novelty, in the sense that the invention was not previously known to the public; and (iii) nonobviousness, or inventive step, in that the invention constitutes an acknowledged extension of prior knowledge.

2. Petty Patents or Utility Models

A limited number of countries allow another form of patent, the petty patent, otherwise referred to as utility model protection. While the requirements of usefulness, novelty, and inventive step must still be met, they are interpreted differently. Petty patents are characterized, first, by a shorter duration of protection, usually between 4 and 7 years. Second,

they are seldom subjected to examination. Third, the inventive step required is minimal. In other words, a petty patent may be issued when only a modest improvement on existing products is provided. A petty patent can be issued more rapidly and costs less than a utility patent.

C. Plant Breeders' Rights

PBRs, otherwise referred to as plant variety protection (PVP) protect against the unauthorized use of the protected varieties. The requirements for plant variety protection are similar to those for utility patents but are less extensive. They include novelty, distinctiveness, uniformity or homogeneity, and stability. A variety must also be given a name by which it can be identified.

To meet the novelty requirement, the variety must not have been offered for sale or marketed in the country of application, or in another country, for more than 4 years. To establish distinctness, which is the principal basis on which PBRs are awarded, the variety must be clearly distinguishable, by one or more important characteristics, from any variety whose existence is a matter of common knowledge. Uniformity requires that important characteristics are uniform across a single planting, and stability requires that the new variety reproduce true to form over repeated propagation.

In contrast to the practice regarding patent applications, new plant varieties are generally subjected to official testing. In many countries, PVP is typically administered by national organizations responsible for seed quality control and variety testing. In others, national patent offices both receive applications for and grant PBRs, but delegate the technical examination to specialists of the Ministry of Agriculture. In the US, the protection of asexually reproduced varieties is the responsibility of the patent office, but the protection of sexually produced varieties is the responsibility of the Plant Variety Protection Office of the US Department of Agriculture.

While PBRs are considered a weaker form of IPR than patents, each successive revision of UPOV has strengthened the scope of protection provided to plant breeders. The latest (1991) version differs in a number of important ways from the earlier 1978 version. These concern, in particular, the scope and duration of protection, the rights of plant breeders, farmers' privilege, and the concept of essentially derived variety.

Under the 1978 Convention, member countries initially were obliged to provide protection for only five species, with gradual progression to a minimum of 24 plant species after 8 years. Under the 1991 revision (Article 3), countries are required to provide protection for all plant genera and species. Five years are allowed to reach this extent of protection for countries that are already members of the Convention; for new members the period is extended to 10 years.

In 1978, protection was granted for a minimum period of 18 years for trees or vines, and 15 years for all other plants. Under the 1991 revision, minimum periods have been increased to 25 years for trees or vines and 20 years for all other plants.

Under the 1978 Convention, it is the plant breeder who must authorize the commercial production of the reproductive or vegetative propagating material of the new plant variety, the sale and marketing of the propagating material, the repeated use of the new plant variety for the commercial production of another variety, and commercial use of ornamental plants or plant parts as propagating material in the production of ornamental plants or cut flowers.

In accordance with the 1978 Convention, PBRs cover the production and sale of reproductive or vegetative propagating material of the new variety, but do not extend to the harvested production (e.g., the fruit from a protected variety of fruit tree). Similarly, PBRs apply to production for commercial marketing, but not to the production of propagating material that is not for commercial use. Thus the production of seed by a farmer for subsequent sowing on his or her own farm, which falls beyond the scope of the breeder's protection, is referred to as the "farmers' privilege."

With the 1991 revision, the scope of PBRs was extended not only to the propagating material but also to harvested material (including whole plants and parts of plants) or, in other words, to all production and reproduction of the protected variety. Countries are nevertheless permitted the discretion to exempt from PBRs traditional forms of saving seed on the farm.

Both the 1978 Convention and 1991 revision provide for the so-called *breeder's exemption*. It allows the use of a protected variety as an initial source of variation for creating other new varieties, without the authorization of the breeder. The 1991 revision, however, introduced the concept of *essential derivation*. Varieties that are essentially derived from a protected variety can be protected, but cannot be marketed without the

permission of the breeder of the protected variety from which they are derived.

C. Technology Transfer in Agriculture: Mechanisms and Agents

Technology in agriculture may be transferred in many different forms: in a commercial or market context, in a nonmarket or public good context, or by a combination of market and nonmarket mechanisms. Technology may be in the public domain and freely available to all, or it may be proprietary. It may be transferred through the purchase of an end product (seeds or machinery), or as an input into the agricultural research process (e.g., a patented genetic mapping technique or a patented gene).

The forms by which international transfers of technology are effected are numerous. Table A12.1 lists the principal forms of transfer for genetic technologies. Technology transfers may occur as an input into the research and development (R&D) process (e.g., a micro-organism, gene, or process) or in the form of an end product (transgenic seed or planting material). Although not always clear-cut, a distinction has been made here between commercial and noncommercial transfers of technology. The term commercial does not necessarily imply the private sector because the public sector is sometimes involved in commercial transactions, and vice versa. It should also be recalled that a single technology may be protected by more than one form of IPR (e.g., Golden Rice).

The most common form of transfer of genetic technologies is probably the purchase or import of seeds, principally for cereal and forage crops, fruits and vegetables, and planting material for floriculture products. This applies (i) where countries have an important commercial farming sector, (ii) where a large share of planted area is sown to hybrids, and (iii) where countries are major exporters of particular kinds of agricultural products. In countries with a dual production system (large-scale commercial farming and low-income smallholders), some small-scale farmers purchase seed and are engaged in profitable production. But among low-income, low-input farmers, the major form of technology transfer remains that of the informal exchange of seed, which has been saved on-farm.

Table A12.1: Technology Transfer Mechanisms for Genetic Technologies

Form of Technology Transfer
Commercial Market Transactions
<ol style="list-style-type: none"> 1. Purchase of technology (new seed variety, planting material) 2. Licensing of product or process with royalty payments (e.g., diagnostic kit, mapping technique) 3. Trade secret (inbred, parental lines) 4. Collaborative research and development 5. Bioprospecting agreements 6. Materials transfer agreements
Noncommercial Transactions
<ol style="list-style-type: none"> 1. Training and technical cooperation 2. Collaborative research and development 3. Materials transfer agreements 4. Technology donations 5. Seed exchange among farmers

The transfer or exchange of inbred or parental lines for research is common among commercial companies in OECD member countries. A seed company in, say, Germany might share inbred lines with a seed company in another country, usually under a trade secret arrangement. The transfer of inbred lines from an OECD member country to a developing country is most likely to take place where hybrids are involved or where the receiving country has already introduced PBRs.

Materials transfer agreements (MTAs) are also used extensively to transfer genetic material for research. MTAs are commonly used in the framework of collaborative research, particularly in publicly- or donor-funded research projects and programs where universities or public research institutions are partners. It is also the favored form of technology transfer among and by the international agricultural research centers (IARCs) which, inter alia, are the designated custodians of the world's plant genetic resources.

A growing number of public-private sector partnerships for bioprospecting are being entered into by countries rich in biodiversity. These countries wish to maintain control and ownership over their genetic resources while earning revenue to reinvest in research on their identification, classification, and preservation. The country with the widest

experience in bioprospecting is Costa Rica. It has negotiated a number of agreements for exploration of its genetic resources with industry partners or with consortia consisting of private foundations, private companies, universities, and the National Biodiversity Institute. In these agreements IPRs are negotiated on a case-by-case basis. Basically, the approach ensures that Costa Rica shares the intellectual and economic benefits of technology transfer, and enhances its capacity to add value to its biological and genetic resources. Moreover, any profits from inventions and materials, or products derived from them, are shared in a way that ensures further exploration and conservation in Costa Rica.

A final form of technology transfer is what might best be described as *technology donation*. This refers to situations in which proprietary technology is *donated* to a developing country (usually to a public research organization or government) to be used under specified conditions.

In technology transfer between developed and developing countries, several public and private partners may be involved. These multilateral partnerships may include private firms, national governments, nongovernment organizations (NGOs), and nonprofit private foundations such as the IARCs. Technology may also be transferred by bilateral agreements between governments through multinational organizations, NGOs, or nonprofit foundations.

The diffusion of the Green Revolution technologies—involving public agents from developing countries, public and private agents from industrialized countries, and private nonprofit partners—had a strong public good aspect. That is now being eroded with the extension and strengthening of IPRs.

E. Issues for Asian Countries

The consequences of developments in IPRs are unlikely to be uniformly positive or negative. They will vary from country to country by level of agricultural development and the capacity to stimulate agricultural innovation. Moreover, the consequences are likely to vary from crop to crop, between commercial and food crops, and between different groups of producers. Stronger IPRs will impact technology transfer to farmers differently than it will impact R&D incentives.

If it is true that IPRs stimulate innovation and investment, a wider range and choice of technologies should become available to farmers or

other end users. For farmers considering a new variety, the price of seed will be weighed against the advantages in quality, yield, or pest-and disease resistance. For farmers planting a new seed variety, IPR protection is irrelevant except where their previous rights to save, reuse, or exchange harvested seed are restricted. Even where a variety is not protected, purchase or sales agreements with seed companies can restrict farmers' subsequent use of the seed.

The impact of IPRs on the agricultural research process, whether basic, applied, or adaptive, is unclear. Evidence suggests that IPRs provide an incentive for private sector investment in R&D, but this is not necessarily perceived as a positive development. There are individuals, organizations, countries, and cultures that have ethical difficulties with patenting life forms, or strong reservations about the private sector's commitment to providing appropriate genetic technologies for resource-poor farmers.

One position argues that IPRs/PBRs will lead to greater uniformity and consequently a further narrowing of the genetic base of major crops. It is true that homogeneity is one of the requirements for granting PBRs and that farmers tend to replace the genetic variability of landraces with the more uniform, protected, high yielding varieties or hybrids. This is a widespread trend even in countries that do not at present allow PBRs. It can be argued that market and agronomic forces, rather than PBRs per se, are the major factor leading to genetic erosion and loss of genetic diversity. But it can also be claimed that increased competition resulting from the extension of PBRs will lead to more marked product differentiation. That, in turn, may enhance genetic diversity. PBRs may therefore play only a peripheral role in the erosion of genetic diversity.

Another concern is that IPRs will impede rather than facilitate the exchange of germplasm. The Biodiversity Convention recognizes the sovereign rights of states over their genetic resources and introduced the principle of *prior informed consent* where these resources are supplied to third parties. Furthermore, the IARCs continue to adhere to the principle of free exchange of the plant genetic resources held in their gene banks. Proponents of IPR argue that protection will increase the transfer of genetic material from developed to developing countries, but this remains to be seen. What is clear is that the exchange of germplasm for research is changing from the former free flow to the transfer under different legal or commercial agreements. What remains unclear is how this is likely to affect the volume of exchange.

APPENDIX 13 INCREASED PUBLIC-PRIVATE SECTOR COLLABORATION

A. Introduction

Most governments in Asia have limited resources to finance biotechnology research. The private sector has the knowledge, skills, and capital to solve the problems of small farmers. That points to the need for more public and philanthropic funding for biotechnology research to benefit small farmers. Although private-sector agricultural research has increased rapidly in the industrialized countries during the last decade, it accounts for only a small share of agricultural research in most developing countries. To the private sector, the anticipated gains are unlikely to cover costs. Intervention through financial incentives or policy instruments then is essential to bring about change.

Successful adaptation of biotechnology for the benefit of poor farmers and consumers in Asia will require establishing or strengthening appropriate institutions to assess and manage public health and environmental risks. In addition, countries will need appropriate policies relating to industrial competitiveness, international trade, and intellectual property if they want to use the new technologies to help advance food security and reduce poverty.

B. Changing Public-Private Sector Balance in Agricultural Innovation

In industrialized and developing countries alike, the roles of the public and private sectors in agricultural innovation, and the balance between the two, have been transformed in recent years. In industrialized countries, public sector financing of agricultural research has generally declined or stagnated in recent years, while private sector investment has increased. That is particularly marked with respect to biotechnology, where research, development, and marketing have been spearheaded by the private sector. Private companies remain at the forefront in advanced research, for example, in transgenics and genomics.

In contrast to the situation in industrialized countries, in most Asian countries the public sector continues to play the major role, not only in agricultural research but often in technology development and dissemination. In biotechnology in Asia, multinational companies are present and concentrate on promising market areas such as hybrid and transgenic crops. They tend to ignore staple crops or products of particular relevance to poor farmers. Hence staple crops such as rice, tropical maize, papaya, cassava, etc. have come to be known as orphan crops. Except for tissue culture and micropropagation, few local, private companies are active in biotechnology.

What then are the prospects for public-private sector collaboration to enhance the development and delivery of biotechnology to Asia's poor farmers?

C. Respective Roles of the Public and Private Sectors

Examination of the roles of the public and private sectors suggests a relatively clear division in some areas, but complementarities in others (CIMMYT 2000). Multinational companies are likely to focus on the higher end of the spectrum in biotechnology research, i.e. transgenics and genomics. They are also likely to concentrate on the development of new crop varieties, or animal health and reproduction technologies where profits can be anticipated in the short term.

In contrast, the conservation of genetic resources will remain a public sector activity. Public research institutions will continue to produce breeding material for varieties adapted locally.

The prospects for public-private sector cooperation and alliances will likely vary by the level of agricultural development in individual countries, the size of the market, types of crops, and types of farmers.

The relative strengths of each provide the basis for complementarities. For example, public research institutions will continue to be an important source of germplasm for private sector development of varieties, or for the adaptation of imported varieties to local germplasm and production conditions. There are also clear complementarities between national agricultural research systems or international agricultural research centers and the private sector in research areas such as functional genomics, where the public institutions have a large knowledge base of indigenous genetic material.

D. Examples of Public-Private Sector Collaboration in Asia

Public-private sector partnerships take a wide variety of forms. In India, an Indian-Swiss project funded by the Swiss Development Corporation involves Swiss research institutes or universities, Indian public research institutes, and private Indian companies in research, development, and production of biofertilizers and biopesticides.

In Thailand a partnership between an industry consortium and BIOTEC, the national public biotechnology institute, brought about the development and commercialization of new molecular diagnostics for the control of virus diseases in shrimp.

The Papaya Biotechnology Network aims to produce transgenic papaya with resistance to papaya ringspot virus disease. Five Asian countries are involved: Indonesia, Malaysia, the Philippines, Thailand, and Viet Nam. The project encompasses research and capacity building for biosafety and intellectual property rights (IPR). It involves proprietary technologies brokered by the International Service for the Acquisition of Agri-biotech Applications (ISAAA).

In the case of the International Rice Genome Sequencing Project, Monsanto has made its gene sequencing files and tools available to a ten-country consortium headed by the Japanese Ministry of Agriculture, Forestry and Fisheries. The countries include Canada; Peoples' Republic of China (PRC); France; India; Republic of Korea; Taipei, China, Thailand; United Kingdom; and the United States. The project, which was completed in early 2001, will lead to better understanding of the genetic control of important factors such as yield, pest resistance, hybrid vigor, quality, and adaptability to different environments.

E. Opportunities for Collaboration

The public sector can expand private sector research for small farmers by converting some of the social benefits to private gains, e.g., by offering to buy exclusive rights to newly developed technology and making it available free or for a nominal charge to small farmers. The private research agency would bear the risks, as it does when developing technology for the market. This arrangement is similar to that proposed by Sachs for developing a malaria vaccine for use in Africa.

Public-private sector research collaboration involving foreign companies is likely to be confined to those areas where companies can draw on complementarities with the public sector such as functional genomics, where they can see future profits and where their intellectual property can be protected. Research collaboration with local companies is likely to be confined in the short term to seed companies, which have access to germplasm from public research institutes for the development of new varieties, or tissue culture companies, which collaborate with universities.

The private sector is likely to be more efficient than the public sector in product development and distribution. Public research institutions are ill-equipped to carry through the entire innovation process from research to farmers' fields. In addition, research budgets do not usually include the often substantial costs of product development. There is also a need to provide incentives for local entrepreneurs to develop new forms of partnership between public research and community organizations, nongovernment organizations, and farmers for product development, field testing, and distribution.

A number of successful Asian experiences have been brought about through the brokering of proprietary technology. Technology brokers or intermediaries can clearly play a useful role in bringing together public and private sector partners, and in negotiating the terms of technology transfer.

Governments have an important role to play in facilitating and stimulating public and private sector cooperation, whether by providing incentives for the development of local companies or ensuring a clear regulatory framework for foreign companies. They may also need to be directly involved in negotiations for the transfer of proprietary technology between foreign companies and the public sector.

While the prospects for public-private sector cooperation are favorable in certain areas, it is unlikely that the private sector will play a major role in the development of the technologies most relevant to the needs of Asia's poor farmers. A key role therefore remains for the public sector and for national governments if biotechnology is to be directed toward the goals of food security and poverty reduction.

Public-private sector cooperation is premised on three key points:

- (i) The private sector is the current main investor, main owner of intellectual property, and the main disseminator of the technology's products, especially for cash crops in Asia.

- (ii) Innovative partnerships are needed for the public sector to multiply benefits for resource-poor farmers by using the technologies developed by the private sector for cash crops to improve orphan crops.
- (iii) The private sector stands ready to cooperate with the public sector.

The fundamental nature of conducting business in the private sector differs from that of the public sector. These key differences need to be recognized at the outset:

- (i) Private sector companies need to demonstrate to their shareholders that cooperation with the public sector improves the company's bottom line either through increasing public acceptance of the company, its products and services, or by reducing public concern or opposition to it.
- (ii) No private sector company will willingly share its trade secrets if in the process its own competitiveness is affected, especially vis-à-vis its competitors in the industrialized world.
- (iii) Companies focus on much shorter term targets than public sector institutions; therefore in any cooperative arrangement, time bound expectations need to be clearly specified.

In Asia, the private sector investment in biotechnology is spearheaded by the following companies: Monsanto, Syngenta, Aventis Crop Sciences, and Dupont-Pioneer HiBrid. Eleven countries in Asia have ongoing agricultural biotechnology research and development (R&D) activities in the public sector. The status of developing, testing, and commercializing genetically improved varieties is shown in Table A13.1.

The pipeline of biotechnology improved crops, especially genetically modified crops, is extensive. The anticipation is that many products will be approved for general release or commercialization once the regulatory frameworks are in place. The public sector R&D effort has concentrated on a diverse mixture of crops for both cash and subsistence farmers: rice, maize, cotton, pulses, papaya, sweetpotato, cassava, flowers, and leafy vegetables. The private sector in Asia has focused on cotton, maize, and soybeans, and mainly on the traits associated with lepidopteran insect pest resistance conferred by *Bacillus thuringiensis* (Bt), and herbicide tolerance. Until recently, at least two

companies had programs to genetically modify rice, but these have now been discontinued.

In the PRC, the private sector has engaged local entities to form joint ventures aimed at producing genetically improved seeds of cotton and maize. In Indonesia, herbicide tolerant maize, cotton, and soybean have been field tested by the private sector under government supervision. In the Philippines, Bt maize has been field tested by two companies, and in Thailand both cotton and maize were tested. In India, extensive trials on Bt cotton have been conducted by the joint venture between MAHYCO and Monsanto. The private sector does not appear to have plans to commercialize genetically modified crops in countries such as Malaysia and Viet Nam because of small market size or intellectual property (IP) related issues.

F. The Nature of Public-Private Sector Cooperation

Public-private sector cooperation in agricultural biotechnology has extended to the following areas:

- (i) Fostering public acceptance of biotechnology.
- (ii) Increasing R&D capacity in the public sector.
- (iii) Technology sharing and donations.
- (iv) Cooperative/grant-funded research on ecological and environmental effects of genetically modified crops.
- (v) Advancing the scientific knowledge base for Asian biotechnology.

Fostering Public Acceptance of Biotechnology. There are many examples of public awareness workshops conducted by public sector organizations using resource persons provided by the private sector. The Asia Pacific Crop Protection Association, an industry organization, has financially supported workshops for media persons in which prominent local or foreign scientists have provided information. A key development in communicating biotechnology in Asia is the launching of new biotechnology information centers in India, Indonesia, Republic of Korea, Malaysia, Philippines, and Thailand.

Table A13.1: Status of the Development of Genetically Improved Crop Varieties in Asia

Country	Contained Laboratory Experiments	Open Field Trials	Large Scale Pre-commercialization/ Commercial Production
China, People's Rep. of	+	+	+
India	+	+	+
Indonesia	+	+	+
Japan	+	+	+
Korea, Rep. of	+	+	-
Malaysia	+	+	-
Philippines	+	+	-
Singapore	+	+	-
Taipei, China	+	+	-
Thailand	+	+	-
Viet Nam	+	+	-

+ = in place, - = not in place.

Increasing R&D Capacity in the Public Sector. In regulatory science and framework development, and in IP issues, for example, four companies provided resource persons to the ISAAA-sponsored IP/Technology transfer workshop held in December 1998. Monsanto sponsored four resource persons to the ISAAA/Kasetsart University Food Safety Workshop held January 2001. In applying biotechnology tools, Monsanto and Aventis provided technical resource persons to transformation workshops held by the papaya ringspot virus resistance network in Southeast Asia.

Technology sharing and donations. Private companies are institutionalizing their activities for improved cooperation with the public sector in sharing technology. Monsanto has created a dedicated team to identify technologies for sharing, the appropriate mechanisms for sharing, and the technical support needed for successful use of shared technology. The Golden Rice Project is one example of the multisectoral approach for technology sharing in Asia, in spite of the large number of IP owners. Other examples of private company donations of genes and enabling technologies for R&D use and for general release in developing countries are given below:

- (i) Donation of vitamin D enabling technology for mustard oil improvement in India by Monsanto, to be implemented by the Tata Energy Research Institute and Indian Council for Agricultural Research.
- (ii) Donation of papaya technology to ASEAN countries; delayed senescence technology by ASTRO-ZENECA, and papaya coat protein resistance technology by Monsanto.
- (iii) Donation of the first working draft of the rice genome by Monsanto to the public sector in April 2000.
- (iv) Announcement by Syngenta of first completed rice genome sequence in January 2001, and possible sharing of some of its sequences with the public sector.

Private industry is interested in working with the public sector in generating knowledge on the management and durability of host plant resistance as a crop protection technology. In particular, insect resistance management requires that site-specific knowledge on arthropod community ecology and vegetation ecology be integrated with knowledge on population genetics and evolutionary biology.

The scientific base for impact assessment is not strong in Asia. Although it is possible to use generic/global principles for risk assessment, benefit assessment has to be site specific because it requires that farm and farmer factors be incorporated into the analyses. The private sector has much published and unpublished information on impact assessment as it pertains to the less diverse cropping systems of the industrialized world. The complex ecosystems of Asian smallholder farmers require that there be a pooling of resources to allow adequate coverage of issues.

GLOSSARY

Apomixis. Reproduction involving specialized generative tissue but not dependent on fertilization.

***Bacillus thuringiensis* (Bt).** Bacteria inserted into the gene of a crop to confer crop-specific resistance to specific pests through the production of a specific toxin.

Biofertilizers. Fertilizers produced through the use of organic materials (crop residue, animal waste, urban waste, etc.) rather than chemical reagents.

Bioinformatics. The assembly of data from genomic analysis into accessible forms, involving the application of information technology to analyze and manage large data sets resulting from gene sequencing or related techniques.

Biopesticides. Pesticides produced through the use of parts of plants or animals, rather than chemical reagents.

Biotechnology. Any technique that uses living organisms or substances from those organisms to make or modify a product, to improve plants or animals, or to develop microorganisms for specific uses. These techniques include the use of new technologies such as recombinant DNA, cell fusion, and other new bioprocesses.

Chromosome(s). The physical structure(s) within a cell's nucleus, composed of a DNA-protein complex, and containing the hereditary material i.e. genes; in bacteria the DNA molecule is a single closed circle (without protein).

Diagnostics. The use of molecular characterization to provide more accurate and quicker identification of pathogens.

deoxyribonucleic acid (DNA). The molecule that is the repository of genetic information in all organisms (with the exception of a few viruses). The

information coded by DNA determines the structure and function of an organism.

Functional genomics. The knowledge that converts the molecular information represented by DNA into an understanding of gene functions and effects: how and why genes behave in certain species and under specific conditions. To address gene function and expression specifically, the recovery and identification of mutant and over-expressed phenotypes can be employed. Functional genomics also entails research on the protein function (proteomics) or, even more broadly, the whole metabolism (metabolomics) of an organism.

Gene. The fundamental physical and functional unit of heredity, the portion of a DNA molecule that is made up of an ordered sequence of nucleotide base pairs that produces a specific product or have an assigned function.

Gene chips (also called DNA chips) or microarrays. Identified expressed gene sequences of an organism can, as expressed sequence tags or synthesized oligonucleotides, be placed on a matrix. This matrix can be a solid support such as glass. If a sample containing DNA or RNA is added, those molecules that are complementary in sequence will hybridize. By making the added molecules fluorescent, it is possible to detect whether the sample contains DNA or RNA of the respective genetic sequence initially mounted on the matrix.

Genetic code. The code that translates information contained in messenger RNA into amino acids. Different triplets of bases (called *codons*) code for each of 20 different amino acids.

Genetic engineering. Technologies (rDNA technologies) used by scientists to isolate genes from an organism, manipulate them in the laboratory, and insert them into another organism.

Genomics. The molecular characterization of all the genes in a species.

Genotype. The genetic constitution of an organism as distinguished from its physical appearance (phenotype).

Germplasm. The total genetic variability, represented by germ cells or seeds, available to a particular population of organisms.

High throughput (HTP) screening or analysis. Screening techniques that allow for a fast and simple test for the presence or absence of a desirable structure, such as a specific DNA sequence, and the expression patterns of genes in response to different stimuli. HTP screening often uses DNA chips or microarrays and automated data processing for large-scale screening, for example to identify new targets for drug development.

Hybrid. An offspring of a cross between two genetically unlike individual plants or animals.

Intellectual property. That area of the law involving patents, copyrights, trademarks, trade secrets, and plant variety protection.

Molecular breeding. Identification and evaluation of useful traits in breeding programs by the use of marker-assisted selection.

Recombinant DNA. Hybrid DNA sequences assembled in vitro from different sources; or hybrid DNA sequences from the same source assembled in vitro in a novel configuration.

Single nucleotide polymorphisms (SNPs). The most common type of genetic variation. SNPs are stable mutations consisting of a change at a single base in a DNA molecule. SNPs can be detected by HTP analyses.

Species. Reproductive communities and populations that are distinguished by their collective manifestation of ranges of variation with respect to many different characteristics and qualities.

Tissue culture. The propagation of tissue removed from organisms in a laboratory environment that has strict sterility, temperature and nutrient requirements.

Transformation. The introduction of one or more genes conferring potentially useful traits into plants, livestock, fish and tree species.

Transgene. The specific gene transferred when rDNA technology is used to introduce a gene from either the same or a different species.

Transgenic animals or plants. Animals or plants whose hereditary DNA has been augmented by the addition of DNA, from a source other than parental germplasm, in a laboratory using recombinant DNA techniques

Vaccine technology. Use of modern immunology to develop rDNA vaccines for improved control of animal and fish disease.

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