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 (*Arabodopsis*) 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, acasias, 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 CHINA[4]

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

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[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 INDIA[5]

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 microorganisms. 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.

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[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 worlds 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 INDONESIA[6]

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.

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[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 *Aspergillus* 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	Dexstranase, 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 Meiiji 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 MALAYSIA[7]

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 l985 and l995 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

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[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

NDB 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 *Aspergillus niger* 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.

[a] Funded 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 Goniothalamin Through Bioreactor Propagation for Clinical Trial
1998	Commercial Production of Bacterial Innoculants as Biofertilizer and Enhancer
	Further Improvement of Pasteurella Spray Vaccine Against Pneumonic Pasteurllosis 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 *Bacillus sphaericus*, a Mosquito Control Agent
1999	Production of Molecular Biological Reagents for Local Market
	Commercialization of *Brugia malayi* 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 Boval 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 (*Tectona grandis*)
	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 PAKISTAN[8]

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.

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[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*, *Azospirillium,* 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 *Azospirillium* 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 Innoculants, 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 PHILIPPINES[9]

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

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[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 GIOs 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 GIOs, 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 genetically 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 THAILAND[10]

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

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[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, livestock, 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 domestication 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 anerobic 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 solacearum).* 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 sphericus*. 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 GIOs. Permission from the Ministry of Agriculture is required to perform field testing of transgenic plants brought into Thailand. The following GIOs 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 GIOs 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 NAM[11]

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

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[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 Agricultural 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	• 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, *Fusarium* ear rot, maize streak virus, *Striga*). • QTLs identified for low soil pH and aluminum toxicity tolerance, stem borer, fall armyworm, *Fusarium moniliforme*, downy mildew, and *Striga* resistance; potential application for maize streak virus. • Linkage maps. • Protocol for maize Bt and herbicide resistance. • DNA chip and microarray technologies.
Rice	IRRI	• 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.,. *Xa21*); 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 *Agrobacterium* 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. • *Knockout* populations; near isogenic lines, recombinant inbred lines; cDNA libraries; DH populations (isogenic lines and pyramids); *indica* BAC library.
Spring Bread Wheat	CIMMYT	• DH (maize system) for breeding, DHs being produced from key crosses; embryo culture for trans formation. • Molecular characterization (limited by cost).

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

Crop	Center	Research and Applications
		• Markers used (RFLPs, RAPDs, SSRs, AFLPs - especially with nonradioactive detection); MAS (SSR) used for BYDV; MAS for enhancing nonhomologous recombination (*Ph1* gene). • Finalizing marker for high protein gene and for CCN; sought *Vrn/Ppd* development genes; preliminary markers for resistance genes (leaf and stripe rust, *Fusarium* 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	• Testing DH system. • Initiating MAS, QTL. • Initiating transformation.
Sorghum	ICRISAT	• Identification of molecular markers for *Striga* resistance. • Identification of QTLs for mildew resistance.
Pearl Millet	ICRISAT	• 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	• 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	• 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
		• Transformation for potato tuber moth resistance; work on bacterial wilt resistance. • *Rxadg* and *Rxacl* genes cloned. • BAC library containing Rysto gene.
Sweetpotato	CIP	• 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	• Micropropagation. • Molecular markers for diversity studies and characterization; microsatellite primers. • Initial work on genome mapping.
Chickpea	ICRISAT	• Embryo culture. • Molecular markers for diversity analysis. • Preliminary, reasonably-saturated, marker-based chickpea linkage map developed. • Transformation protocol available.
Groundnut	ICRISAT	• 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	• Work elsewhere on markers and linkage maps. • Transformation protocol, particularly regeneration under investigation.

AFLP = amplifiied fragment length polymorphism, Bt = *bacillus thuriengiensis*, 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	12	na	14	8	2	38
Professional Staff						
Years in Crop I 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 International 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
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
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.