II Scientific Context

A. Promethean Science

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

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

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

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

B. Definition, History, and Scope of Biotechnology

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

The key components of modern biotechnology are listed below.

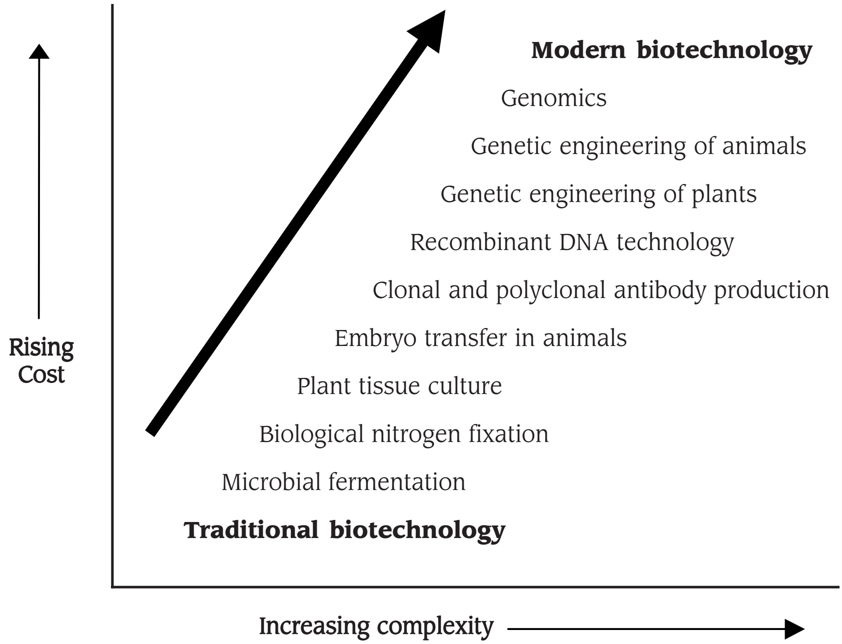
(i) Genomics: The molecular characterization of all genes in a species.
(ii) Bioinformatics: The assembly of data from genomic analysis into accessible forms, involving the application of information technology to analyze and manage large data sets resulting from gene sequencing or related techniques.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

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

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

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

Figure 2.1 Gradient of Biotechnologies



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

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

C. Economic Concentration in Agricultural Biotechnology

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

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

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

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

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

Source: Adapted from Persley (1990).

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

The commercialization and distribution of new agricultural biotechnology products, particularly transgenic crops, is also concentrated in Organisation for Economic Co-operation and Development (OECD) member countries, with a few exceptions (James 2000). These products are for the most part crops of economic importance in industrial country agricultural production and in world trade in agricultural commodities, mainly soybean, maize, cotton, and canola. During the past five years, the area under GMOs[3] has increased rapidly from 1.7 million ha to 44.4 million ha, 75 percent of which are in the US. The remaining 25 percent are distributed in both developed and developing countries, including Argentina, Australia, Bulgaria, Canada, PRC, France, Germany, Mexico, Portugal, Romania, South Africa, Spain, Ukraine, and Uruguay (Appendix 2).

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

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

D. Applications of Biotechnology

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

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

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

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

Table 2.2: Summary of Applications of Modern Biotechnology to Agriculture

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

Source: Consultants' assessment.

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

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