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DISTRIBUTION OF BENEFITS FROM AGRICULTURAL BIOTECHNOLOGY

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Abstract

Agriculture is expected to feed an increasing human population, forecast to reach 8000 million by 2020, of whom 6700 will be in the developing countries. New technologies, such as biotechnologies, if properly focused, offer a responsible way to enhance agricultural productivity for now and the future**.** Broader than genetic engineering and gene splicing, biotech includes tissue, cell, and embryo culture; protoplast fusion; bio-regulation or hormonal control of physiological and metabolic processes; production of gene-controlled products; directed plant breeding; and fermentation processing. In broad sense, the definition of biotechnology covers many of the tools and techniques that are commonplace in agriculture and food production. Interpreted in a narrow sense, which considers only new rDNA techniques, molecular biology and reproductive technological applications, the definition covers a range of different technologies such as gene manipulation and gene transfer, DNA typing and cloning of plants and animals. When appropriately integrated with other technologies for the production of food, agricultural products and services, biotechnology can be of significant assistance in meeting the needs of an expanding and increasingly urbanized population in the next millennium. The purposes for genetically modifying crops using recombinant DNA technology fall into a few broad classes: (1) improved plant protection from external pressures (i.e., insects, weeds, disease, or other environmental stresses), (2) improved quality of food products (enhanced vitamin/mineral content, improved taste, increased shelf life), and (3) development of new products such as industrial compounds and pharmaceutical proteins. The extent to which modern biotechnology will be fully utilized for the benefit of consumers depends on support for innovation and improvement in farming and food production, on the one hand, and on support for scientifically sound regulatory policies that protect against tangible food safety risks, on the other. It could be concluded that steps must be taken to meet the urgent need for sustainable practices in world agriculture if the demands of an expanding world population are to be met without destroying the environment or natural resource base. In particular, GM technology, coupled with important development in other areas, should be used to increase the production of main food staples, improve the efficiency of production, reduce the

environmental impact of agriculture, and provide access to food for small-scale farmers. Also, disparities in intellectual property rights (IPR) protection across countries affect the distribution of benefits. Consumer resistance toward genetically modified organisms (GMOs) and the issues of labeling and market segregation complicate the economic evaluation of biotechnology innovations, and a number of related regulation and public policy issues have to be discussed.

Introduction

Agriculture is expected to feed an increasing human population which numbered approximately 1.6 billion in 1900, forecast to reach 8 billion by 2020, of whom 6,7 billion will be in the developing countries, and it will reach 10 billion by 2030. Although the rate of population growth is steadily decreasing, the increase in absolute numbers of people to be fed may be such that the carrying capacity of agricultural lands could soon be reached given current technology The United Nations Food and Agriculture Organization estimates world food production will have to double on existing farmland if it is to keep pace with the anticipated population growth. New technologies, such as biotechnologies, if properly focused, offer a responsible way to enhance agricultural productivity for now and the future**.** Biotechnology can help meet the ever-increasing need by increasing yields, decreasing crop inputs such as water and fertilizer, and providing pest control methods that are more compatible with the environment.

Biotechnology has been labeled "a misleading expression because it conveys a singularity or unity to what is actually a tremendously diverse set of activities and range of choices ‘’ (Buttel, 1985). Biotechnology processes and products are so diverse and have so little in common with one another that it is difficult to construct valid generalizations about them. Broader than genetic engineering and gene splicing, biotech includes tissue, cell, and embryo culture; protoplast fusion; bio-regulation or hormonal control of physiological and metabolic processes; production of gene-controlled products; directed plant breeding; and fermentation processing."

Michael Fox provides a chronological presentation of the significant biotechnology events leading up to the present day. Fox begins with the breeding experiments by Mendel in 1869. (Fox, 1992) feels that the roots of biotechnology, especially as it relates to traditional plant breeding, can be traced back to the earliest days of agriculture and the domestication of plants and animals. Keeney, however, points out, "In contrast, the new agricultural biotechnologies provide the tools for molecular and cellular approaches to altering plants and animals." (Keeney, 1998). This is a big distinction between more traditional plant and animal breeding and biotechnology. The traditional methods were limited to using only materials that were biologically similar. With today's biotechnology capabilities, scientists are able to construct animals and plants that would never have been possible using conventional breeding techniques. Biotechnology provides powerful tools for sustainable development of agriculture, fisheries and forestry, as well as the food industry. When appropriately integrated with other technologies for the production of food, agricultural products and services, biotechnology can be of significant assistance in meeting the needs of an expanding and increasingly urbanized population in the next millennium.

What is Biotechnology?

In broad sense, the definition of biotechnology covers many of the tools and techniques that are commonplace in agriculture and food production. Interpreted in a narrow sense, which considers only new DNA techniques, molecular biology and reproductive technological applications, the definition covers a range of different technologies such as gene manipulation and gene transfer, DNA typing and cloning of plants and animals.

For example, recombinant DNA (rDNA) technology offers the potential for expanding the world's food supply and biotechnology-derived food crops have increased yields and better resistance to pests, disease, and environmental stress.
Over the past quarter-century, rDNA technology has given us life-saving drugs and provided a range of precise genetic diagnostic tools to identify a number of conditions at an early stage. The impact of public opinion to the application of rDNA to medical problems was rapidly embraced by researchers and by the public. However, the same technology applied to agriculture is facing resistance by some people who think it might be inherently hazardous. Since the basic technology is the same, it is difficult to see why it might be hazardous to use biotechnology to make foods but not to make medicines. In any case biotechnology is used, for example, to develop plants that make medicines.

The extent to which modern biotechnology will be fully utilized for the benefit of consumers depends on support for innovation and improvement in farming and food production, on the one hand, and on support for scientifically sound regulatory policies that protect against tangible food safety risks, on the other.
Biotechnology using similar genetic techniques in the field of medicine and human health is well accepted by the public and professional communities as a safe and effective means to provide more and better treatment. With the continuing accumulation of evidence of safety and efficiency, and the complete absence of any evidence of harm to the public or the environment, more and more consumers are becoming as comfortable with agricultural biotechnology as they are with medical biotechnology.

What is Agricultural Biotechnology?

Agricultural biotechnology, in its most general sense, refers to any technique that manipulates plants or animals (or their products) to achieve a specified goal. By this broad definition, improvement of food crops and animals through selective breeding, and processes such as beer/wine fermentation, cheese production, and manufacturing of cloth from wool or cotton are examples of agricultural biotechnology. However, the term "biotechnology" is most often linked to modern science, and includes topics such as molecular breeding, tissue culture techniques, and rDNA technology - the latter often referred to as genetic engineering. Plant genetic engineering involves inserting a gene (or sequence of genes), copied from a bacteria, virus, plant, animal, or human, into a plant. The gene of interest is often referred to as a "transgene", if the gene moves across species; the genetically modified plant is known as a "transgenic" plant or more generally as a genetically modified organism (GMO).

The purposes for genetically modifying crops using recombinant DNA technology fall into a few broad classes: (1) improved plant protection from external pressures (i.e., insects, weeds, disease, or other environmental stresses), (2) improved quality of food products (enhanced vitamin/mineral content, improved taste, increased shelf life), and (3) development of new products such as industrial compounds and pharmaceutical proteins.

Past studies on benefits and costs of agricultural technologies

There have been many previous analyses of the benefits and costs of agricultural technologies (See Evenson, 2000 for recent reviews) and a few economic assessments of modern agricultural biotechnologies (e.g., Falk-Zepeda, 2000, Traxler, and Nelson, 2000; Qaim, 1999, 2000)). Most studies have focused on the benefits of technologies generated through public sector research and extension. The results have generally suggested significant positive benefits to agricultural research and development in the aggregate, with producers who adopt early and low-income consumers benefiting the most. However, biotechnology, with its significant private sector participation in research, can generate its own distinct benefit patterns, especially if imperfectly competitive firms can retain profits from innovations (Moschini and Lapan, 1997). Furthermore, growing consumer concern is causing government regulators to move cautiously - perhaps justifiably - affecting the speed with which technologies become available and are adopted. Therefore, it is essential to evaluate public opinion with respect to agricultural biotechnologies and to incorporate those opinions into analyses of the benefits and costs of technological use.

Benefits from Biotechnology

Agriculture before GMOs

Change brought about by science and technology has shaped agriculture since the industrial revolution, and the speed of the induced economic change has picked up pace in this century. Chemicals, fertilizers, pesticides, and herbicides have also made a difference, bringing a newer class of extremely useful production inputs to agriculture. Breeders have provided an impressive array of improved crop varieties, the achievements of hybrid corn being a classic example of success. The difficulties of systematic genetic improvements in animal science have been mastered, along with the introduction of a number of techniques for efficient animal husbandry. To briefly review some of the effects of innovation in agriculture, consider the evolution of productivity in the United States in the twentieth century. The U.S. agricultural output in this period has increased fivefold, whereas overall input use has stayed roughly constant; thus, the U.S. sector has experienced sizable “productivity gains,” i.e., increased efficiency. The output trend is easily rationalized. For example, over the last 50 years the yield of major crops such as corn and soybeans has increased more that threefold; milk-per-cow has increased nearly fivefold. Naturally, such production gains have required increased use of some factors. In particular, the use of fertilizers, pesticides, and other chemical inputs has increased dramatically, and more and better machines have continued to change the way basic production tasks are performed. For example, in 1910 there were only 1,000 tractors.

The Need for GM technology in Agriculture

Today there are some more than 800 million people (18% of the population in the developing world) who do not have access to sufficient food to meet their needs (Pinstrup-Anderson and Pandya-Lorch, 2000), primarily because of poverty and unemployment. Malnutrition plays a significant role in half of the nearly 12 million deaths each year of children under five in developing countries (UNICEF, 1998). In addition to lack of food, deficiencies in micronutrients, especially vitamin A, iodine, and iron) are widespread. Dramatic advances are required in food production, distribution and access if we are going to address these needs. Some of these advances will occur from non-GM technologies, but others will come from advances offered by GM-technologies. Achieving the minimum necessary growth in total production of global staple crops, as maize, rice, wheat, cassava, yams, sorghum, potatoes and sweet potatoes, without increasing land under cultivation will require substantial increases in yields per unit area. Increases in production are also needed in other crops, such as legumes, millet, cotton, bananas and plantains. Therefore it is important to increase yield on land that already intensively cultivated. However, increasing production is only one part of the equation. Income generation, particularly in low-income areas, together with the more effective distribution of food stocks, are equally, if not more, important. GM technologies are relevant to both these elements of food security. In spite of the great achievements occurred with the green revolution, there are still heavy losses of crops owing to biotic (e. g., pests and diseases) and abiotic (e.g., salinity and drought) stresses. There are fewer options available than previously to address current problems through traditional breeding techniques, although it is recognized that these techniques will continue to be important in the future. The benefits from transgenic plants include increased flexibility in crop management, decreased dependency on chemical pesticides and soil disturbances, enhanced cost of food and higher nutritive value. Concerns regarding GM technology range from its potential impact on human health and the environment to concerns about private sector monopolies of the technology. It is essential that such concerns are addressed if we are to reap the potential benefits of this new technology

Crop Biotechnology

Farmers and plant breeders have relied for centuries on crossbreeding, hybridization and other genetic modification techniques to improve the yield and quality of food and fiber crops and to provide crops with built-in protection against insect pests, disease-causing organisms and harsh environmental conditions. By selectively sowing seeds from plants with preferred characteristics, the earliest agriculturists performed genetic modification to convert wild plants into domesticated crops long before the science of genetics was understood.

As our knowledge of plant genetics improved, we purposefully crossbred plants with desirable traits (or lacking undesirable characteristics) to produce offspring that combine the best traits of both parents. In today's world, virtually every crop plant grown commercially for food or fiber is a product of crossbreeding, hybridization or both. Unfortunately, these processes are often costly, time consuming, inefficient and subject to significant practical limitations. For example, producing corn with higher yields or natural resistance to certain insects takes dozens of generations of traditional crossbreeding, if it is possible at all.

The tools of biotechnology allow plant breeders to select single genes that produce desired traits and move them from one plant to another. The process is far more precise and selective than traditional breeding in which thousands of genes of unknown function are moved into our crops.

Biotechnology also removes the technical obstacles to moving genetic traits between plants and other organisms. This opens up a world of genetic traits to benefit food production. We can, for example, take a bacterium gene that yields a protein toxic to a disease-causing fungus and transfer it to a plant. The plant then produces the protein and is protected from the disease without the help of externally applied fungicides.

Improving Crop Production

The crop production and protection traits agricultural scientists are incorporating with biotechnology are the same traits they have incorporated through decades of crossbreeding and other genetic modification techniques: increased yields; resistance to diseases caused by bacteria, fungi and viruses; the ability to withstand harsh environmental conditions such as freezes and droughts; and resistance to pests such as insects, weeds and nematodes.

Natural Protection for Plants

Just as biotechnology allows us to make better use of the natural therapeutic compounds our bodies produce, it also provides us with more opportunities to partner with nature in plant agriculture. Biotechnology will also open up new avenues for working with nature by providing new biopesticides, such as microorganisms and fatty acid compounds, that are toxic to targeted crop pests but do not harm humans, animals, fish, birds or beneficial insects. Because biopesticides act in unique ways, they can control pest populations that have developed resistance to conventional pesticides. A biopesticide farmers (including organic farmers) have used since the 1930s is the microorganism *Bacillus thuringiensis*, or Bt, which occurs naturally in soil. Several of the proteins the Bt bacterium produces are lethal to certain insects, such as the European corn borer, a prevalent pest that costs the United States $1.2 billion in crop damage each year. Bt bacteria used as a biopesticidal spray can eliminate target insects without relying on chemically based pesticides. Using the flexibility provided by biotechnology, we can transplant the genetic information that makes the Bt bacterium lethal to certain insects (but not to humans, animals or other insects) into plants on which that insect feeds. The plant that once was a food source for the insect now kills it, lessening the need to spray crops with chemical pesticides to control infestations.

HerbicideTolerance

Good planting conditions for crops will also sustain weeds that can reduce crop productivity as they compete for the same nutrients the desired plant needs. To prevent this, herbicides are sprayed over crops to eliminate the undesirable weeds. Often, herbicides must be applied several times during the growing cycle, at great expense to the farmer and possible harm to the environment. Using biotechnology, it is possible to make crop plants tolerant of specific herbicides. When the herbicide is sprayed, it will kill the weeds but have no effect on the crop plants. This lets farmers reduce the number of times herbicides have to be applied and reduces the cost of producing crops and damage to the environment.

Resistance to Environmental Stresses

In addition to the biological challenges to plant growth and development just described, crops plants must contend with abiotic stresses nature dispenses regularly: drought, cold, heat and soils that are too acidic or salty to support plant growth. While plant breeders have successfully incorporated genetic resistance to biotic stresses into many crop plants through crossbreeding, their success at creating crops resistant to abiotic stresses has been more limited, largely because few crops have close relatives with genes for resistance to these stresses.

The crossbreeding limitation posed by reproductive compatibility does not impede crop biotechnology; genes found in any organism can be used to improve crop production. As a result, scientists are making great strides in developing crops that can tolerate difficult growing conditions. For example, researchers have genetically modified tomato and canola plants that tolerate salt levels 300 percent greater than non-genetically modified varieties. Other researchers have identified many genes involved in cold, heat and drought tolerance found naturally in some plants and bacteria. Scientists in Mexico have produced maize and papaya that are tolerant to the high levels of aluminum that significantly impede crop plant productivity in many developing countries.

Increasing Yields

In addition to increasing crop productivity by using built-in protection against diseases, pests, environmental stresses and weeds to minimize losses, scientists use biotechnology to improve crop yields directly. Researchers at Japan's National Institute of Agrobiological Resources added maize photosynthesis genes to rice to increase its efficiency at converting sunlight to plant starch and increased yields by 30 percent. Other scientists are altering plant metabolism by blocking gene action in order to shunt nutrients to certain plant parts. Yields increase as starch accumulates in potato tubers and not leaves, or oil-seed crops, such as canola, allocate most fatty acids to the seeds.

Biotechnology also allows scientists to develop crops that are better at accessing the micronutrients they need. Mexican scientists have genetically modified plants to secrete citric acid, a naturally occurring compound, from their roots. In response to the slight increase in acidity, minerals bound to soil particles, such as calcium, phosphorous and potassium, are released and made available to the plant. Nitrogen is the critical limiting element for plant growth and, step-by-step, researchers from many scientific disciplines are teasing apart the details of the symbiotic relationship that allows nitrogen-fixing bacteria to capture atmospheric nitrogen and provide it to the plants that harbor them in root nodules.

Plant geneticists in Hungary and England have identified the plant gene and protein that enable the plant to establish a relationship with nitrogen-fixing bacteria in the surrounding soil. Microbial geneticists at the University of Queensland have identified the bacterial gene that stimulates root nodule formation. Collaboration among molecular biologists in the European Union, United States and Canada yielded the complete genome sequence of one of the nitrogen-fixing bacteria species. Protein chemists have documented the precise structure of the bacterial enzyme that converts atmospheric nitrogen into a form the plant can use.

Forest Biotechnology

Throughout the world, wood provides us with fuel, construction materials and paper, and its supplies are dwindling rapidly. Wood products are currently a $400 billion global industry, employing 3 million people. Demand for wood products is expected to increase, even as major economies, such as Europe and Japan, are unable to grow enough trees to meet their current demand. According to the U.N. Food and Agriculture Organization, world demand for wood products in 2010 will be about 1.9 billion cubic meters, almost 20 percent higher than it is now. We must attempt to meet that demand without cutting down the world's remaining forests.

Increasing Productivity
We are using biotechnology to create disease- and insect-resistant trees and to increase their growth rates. Scientists are also learning how to use biotechnology to improve the efficiency with which trees convert solar energy into plant material and to shunt more of that energy into wood production and less into pollen, flowers or seeds. All of these methods of increasing productivity should decrease the pressure on natural forests.

Researchers are looking to other methods for increasing productivity. For example, they are using a biotechnology process in a fungus to fight diseases that infect trees and are working on improving the microorganisms that live on tree roots and provide trees with nutrients, much as nitrogen-fixing bacteria increase the nutrients available to soybeans and alfalfa. In addition, biopesticides have also been used extensively to control forest pests, and we expect progress in insect cell culture to boost the number of biocontrol agents available for forest insect control.

Environmental Benefits
Perhaps a more important economic role for biotechnology in this industry will be found in its changing the way we convert trees to useful products. Extensive research is being conducted to increase a tree's amount of cellulose, the raw material for papermaking, and to decrease the amount of lignin, a tough molecule that must be removed in papermaking. Traditionally, removing lignin from trees has required harsh chemicals and high energy costs, so changing the cellulose:lignin ratio genetically has important environmental implications, as does increasing the growth rate of trees. Because trees absorb carbon dioxide, any advance that allows us to increase tree yields without cutting down forest could have significant positive effects on global warming. Other environmental benefits that biotechnology is providing to the forestry industry include enzymes for

- pretreating and softening wood chips prior to pulping.
- removing pine pitch from pulp to improve the efficiency of paper-making.
- enzymatically bleaching pulp rather than using chlorine.
- de-inking of recycled paper.
- using wood-processing wastes for energy production and as raw materials for manufacturing high-value organic compounds.
- remediating soils contaminated with wood preservatives and coal tar.

Animal Biotechnology

Animals are playing a growing role in the advancement of biotechnology, as well as increasingly benefiting from biotechnology. Combining animals and biotechnology results in advances in four primary areas:

1. Improved animal health through biotechnology.
2. Advances in human health through biotechnology studies of animals.
3. Enhancements to animal products with biotechnology.
4. Environmental and conservation efforts of biotechnology.

Animal biotechnology includes all animals-livestock, poultry, fish, insects, companion animals and laboratory animals-and applications of the scientific tools of genomics, transgenics, and cloning technologies.

Improving Animal Health

The market for biotechnology-based animal health products and services is estimated to be $2.8 billion and expected to grow to $5.1 billion by 2005. As of July 2003, there were 111 animal biotech products, including bacterins and killed virus vaccines. The animal health industry invests more than $400 million a year in research and development.

Farm animals
Biotechnology provides new tools for improving animal health and increasing livestock and poultry productivity. These improvements come from the enhanced ability to detect, treat and prevent diseases and other problems; from better feed derived from transgenic crops designed to meet the dietary needs of different farm animals; and from improved animal breeding.

The animal health industry has developed many effective treatments that can prevent and treat dangerous diseases that could potentially strike entire livestock herds and poultry flocks. Quick diagnosis and treatment of diseases through DNA- and antibody-based tests, coupled with strong preventative measures, help lower production costs and improve overall animal well-being. Additionally, healthier farm animals result in safer and foods for consumers.

- In addition to these existing vaccines, work is being done to develop a vaccine for an African cattle disease called East Coast fever. If successful, this vaccine would be the first against a protozoan parasite and could lead to the development of a malaria vaccine for humans.
- Molecular-based typing of pathogens, such as genetic fingerprinting, allows for the monitoring of the spread of disease within and between herds and can identify the source of an outbreak.
- Genetic analysis of animal pathogens.
- Researchers are developing a vaccine alternative to castration for livestock.

- New DNA tests can identify pigs with the genetic condition porcine stress syndrome, which causes tremors and death under stressful conditions.

- Inherited weaknesses of cattle can be identified with DNA tests, which are currently being used in national breeding herds in Japan. Tests can identify leukocyte adhesion deficiency, which causes repeated bacterial infections, stunted growth and death within the first year of life.
- Factor 13 deficiency, which prevents blood from coagulating normally, can also be identified. Other DNA tests can identify a hereditary condition that produces anemia and retarded growth in Japanese black cattle.

Increasing Livestock Productivity
Livestock producers are always interested in improving the productivity of agricultural animals (milk, eggs, meat, wool) with less input (food), or increased output with the same input. Increasing muscle mass and decreasing fat in cattle and pigs have long been goals of livestock breeders.

Using biotechnology to increase the productivity of livestock is a variation of selective breeding. This through using in vitro fertilization followed by embryo culture, then implanted into a female of the same species-but not necessarily of the same breed. This is known as embryo transplant.

Genomics technology is being applied to improving the conventional breeding of superior animals in order to produce desirable traits. In 2001, genome sequences for cattle, swine, and chicken were completed.

Enhancing Animal Products
Biotechnology can make dramatic improvements to animal products that humans consume and use. Some of these improvements result from vaccines, medicines and diagnostic tests that make animals healthier. However, biotechnology has also made great strides in enhancing animal products at a cellular level through transgenic and cloning technology. Some of these enhancements include:

- Researchers can produce transgenic cows, pigs and lamb with reduced fat and increased lean muscle.
- Genetic mapping projects allow farmers to identify highly productive animals for breeding programs.
- Vaccines have found new uses and can now improve egg production in breeding turkeys. The vaccine stimulates the turkey's immune system to overcome the tendency to stop laying eggs.
- Transgenic cows can now produce "designer milks" with increased levels of protein that can improve the diet of children or affect production of cheese and yogurt. Additionally, scientists are now working to remove from milk the proteins that cause lactose intolerance. It is estimated that 90 percent of the Asian population is lactose intolerant.
- Australian scientists have increased wool production by feeding sheep transgenic lupin, a mainstay of sheep's summer diet.

Biotech versions of several animal-feed crops are under study. These products are designed to improve the quality of protein, oils or energy availability in the final animal food product. One crop is designed to improve shelf life of beef by improving the antioxidant properties of the meat's fats.

Environmental Impacts and Conservation Efforts

Livestock producers are challenged with identifying how to dispose of more than 160 million metric tons of manure annually. Animal manure, especially that of swine and poultry, is high in nitrogen and phosphorus, which can contribute to surface and groundwater pollution. Several crops improved with biotechnology may offer animal feed that decreases phosphorus and nitrogen excretion, total manure excretion and offensive odors.

Further, the Enviro-Pig is a transgenic pig that has a gene added to enhance salivary phytase, thereby improving phosphorus digestibility and retention of phosphorus in pork, with reduced excretion of phosphorus in the manure of the animal. The goal is to reduce the chance of manure contributing to groundwater contamination in areas that surround livestock farms.

Endangered Species Conservation

Biotechnology is also providing new approaches for saving endangered species. Reproductive and cloning technologies, as well as medicines and vaccines developed for use in livestock and poultry, can also help save endangered mammals and birds.

Borrowing biotechnology techniques used by livestock breeders, veterinarians at the Omaha zoo recently used hormonal injections, artificial insemination, embryo culture and embryo transfer to produce three Bengal tiger cubs. A Siberian tigress served as the surrogate mother for these embryos.

In September 2001, researchers at the University of Teramo, Italy, created the first viable clone of an endangered species, the European mouflon. The mouflon is one of the smallest wild sheep in the world. Researchers continue to investigate the use of cloning for other endangered species, such as panda bears and the ox-like gaur. Additionally, a few organizations have created genetic databases to store cryogenically frozen samples of DNA, gametes and cell tissues for later use.

Researchers at the San Diego Zoo have been freezing cells from endangered species since 1975 with the simple objective of studying genetic similarities to other species someday. The possibilities expanded in 1997 with the news that Scottish scientists had cloned a sheep from body cells.

In April 2003, the San Diego Zoo reported the birth of the first healthy clone of an endangered species, the banteng. Additionally, the first cloned deer, reported in December of 2003, may help with conservation efforts.

Recently, Chinese scientists announced that they are close to cloning the Giant Panda using trans-species cloning technology. The Giant Panda is a highly endangered species. Biotechnology techniques for working with endangered species have not been limited to cloning. Some researchers are using genetic samples to study the distribution of species and track the relationships between different groups of animals. These studies may help to prevent excessive interbreeding among small groups of animals. Genetic studies can also help produce a more healthy population of endangered species through increased genetic diversity..

Endangered Plants

Endangered plants may also benefit from the flexibility in problem-solving biotechnology provides. Scientists are developing strategies for resurrecting the American chestnut tree, brought to virtual extinction by chestnut blight, and restoring the Cornish elm tree, 90 percent of which have been destroyed by Dutch elm disease, to Great Britain.

One approach to regenerating populations of chestnuts involves using genomics to identify and isolate genes for blight resistance found in the Chinese chestnut, then adding those genes to the chestnut seedlings that continue to sprout from the trunks of dead chestnut trees. The time frame for creating blight-resistant American chestnuts shrinks to less than five years if plant cell culture and recombinant DNA technology are used.

Distribution of Benefits from GM Technology

GM technology has been used to produce a variety of crop plants to date, some of which have become commercially successful. In countries as United states and Canada the technology centered on increasing shelf life of fruits and vegetables, conferring resistance to pests and viruses, and producing tolerance to specific herbicides. While these traits have had benefits for farmers, it has been difficult for the consumers to see any benefit other than, in limited case, a decreased price owing to reduced cost and increased ease of production (Nelson et al, 1999). A possible exception is the development of GM technology that delays ripening of fruit and vegetables, thus allowing increased length of storage. Framers would benefit from this development by increased flexibility in production and harvest. Consumers would benefit by the availability of fruits and vegetables such as transgenic tomatoes modified to soften much more slowly than traditional varieties, resulting in an improved shelf life and decreased cost of production, higher quality and lower cost. The following examples show how GM technology can be applied to some of specific problems of agriculture, indicating the potential for benefits:

Economic Benefits and Costs of Biotechnology Innovations in Agriculture

As could be expected from truly novel developments, the nature and impact of these new technologies may also have profound economic implications. Biotechnology encompasses a broad array of innovations that affect many industries.

Biotechnology’s current impact on agriculture arises from the recent introduction of improved crops that belong to the class of genetically modified organisms (GMOs).The standard framework that is used to evaluate the economic benefits of agricultural innovations could be extended to assess the economic benefits and costs of biotechnology innovations, and their likely distribution. This is followed by a review of some problems that have been raised by the rapid adoption of biotechnology innovations in agriculture, including a discussion of GMO regulation and related public policy issues. Needless to say, such considerations are at present largely speculative, given the considerable scientific, regulatory, and market uncertainty that surrounds GMOs.

Environmental and Economic Benefits

Beyond agricultural benefits, products of crop biotechnology offer many environmental and economic benefits. As described above, transgenic crops allow us to increase crop yields by providing natural mechanisms of pest control in place of chemical pesticides. These increased yields can occur without clearing additional land, which is especially important in developing countries. In addition, because biotechnology provides pest-specific control, beneficial insects that assist in pest control will not be affected, facilitating the use of integrated pest management. Herbicide-tolerant crops decrease soil erosion by permitting farmers to use conservation tillage.

According to the National Center for Food and Agricultural Policy's 2002 report, in 2001 the eight transgenic crop varieties adopted by U.S. growers increased crop yields by 4 billion pounds, saved growers $1.2 billion by lowering production costs, and reduced pesticide use by 46 million pounds. Four additional transgenic crops had been approved by the 2001 growing season, but growers opted not to plant them. Had they adopted these varieties, their yields would have increased by an additional 1.1 billion pounds and profits by $158 million; and pesticide use would have decreased by another 582,000 pounds.

According to the International Service for the Acquisition of Agri-Biotech Applications, a single transgenic crop, Bt cotton, has led to the following environmental and economic benefits for farmers in developing countries:

- From 1999 to 2000 in China, insecticide usage decreased by 67 percent, yields increased by 10 percent, leading to income gains of $500 per hectare.
- Extensive field trials in India from 1998 to 2001 demonstrated a 50 percent reduction in insecticide spraying, 40 percent increase in yields, which equals an increase in income from $75 to $200 per hectare.

Small farmers in South Africa gained through a 25 percent yield increase and decreased number of insecticide sprays from 11 to four, reducing pesticide costs by $45 per acre. The higher cost of Bt seed (up to $15 per hectare for small farmers) resulted in an average economic advantage of $35 per hectare

Who Benefits from Biotechnology?

It appears that the primary beneficiaries of the first generation biotechnology products are most likely the seed companies that created the products. Additionally, in the case of herbicide tolerance the companies that supply the tolerant herbicides also are the benefactors from the development of the biotech crops.

It also appears that farmers have benefited from biotechnology. Their gains, however, appear to more related to greater ease of production and the ability to cover more acres as opposed to an increase in the profits per acre. The farmer benefits are evidenced by the rapid adoption of this new technology. As noted, in Iowa soybean acres planted to herbicide-tolerant varieties went from zero to more than half the total acreage in just a few years. Farmers definitely perceive a benefit even if their profits are not increasing.

It has been argued that consumers also are the beneficiaries of the first generation biotech products because the increased production leads to lower prices. Whether or not production increases depends upon the crop under consideration. For soybeans, the yields actually are slightly less, while for corn they are slightly higher.

Regardless of the crop under consideration, it is hard to determine whether consumers actually benefit from the first generation biotech products. The prices for the basic commodities covered are already low due to abundant supplies. In addition, government programs that support prices will cost the taxpayers more if the prices continue to drop.

Consumers actually spend only a fraction of their food dollar on these basic commodities. Changes in the price of the basic commodities will have little impact on the prices charged to the consumers. Additionally, a consumer backlash against biotech indicates that, for at least some consumers, the addition of biotech crops is not seen as a benefit but an added risk.

Today's biotech crops and applications are merely the first generation of products. It appears from these examples that the primary beneficiaries are the seed and chemical companies and, to a lesser extent, the farmers. What will happen with the proposed second-generation products remains to be seen.

Why the benefits are different?

Biotechnology is an extremely powerful tool. It has the potential to create many useful products as well as many unforeseen problems. As with any new technology, it must be evaluated carefully. It is not prudent to expect private companies to develop products for the public good. Companies are in the business of making money and the products they pursue are designed for that end. To expect any other result from private research is not appropriate or realistic.

Today the primary benefactors of biotechnology are the seed companies and chemical companies. Farmers appear to be receiving some non-pecuniary benefits. And, in spite of arguments to the contrary, there is only mixed evidence with respect to consumer benefits. There is a question of unknown health effects from the genetically modified products. Health officials have assured the public that this should not a concern, but this is not an entirely satisfactory reassurance to many. Several other externality issues surround the use of biotech crops. Insect and weed resistance will develop faster with the widespread use of these products. There also is the issue of pollen drift that affects people trying to grow either organic commodities or some other type of crop requiring segregation from biotech varieties.

Innovations bring about sizable economic benefits, which are typically shared across various agents, sectors of the economy, and countries. Biotechnology holds the promise of considerable benefits to society at large, through the introduction of more efficient and more environmentally friendly techniques of producing standard crops, and by the development of a potentially exciting array of new products. Not everyone, of course, is bound to gain from the introduction of a new product and/or process. Concerning the features that are likely to be relevant to assess the size and distribution of the benefits and costs of biotechnology innovations, specific conclusions are difficult at this stage, because they depend on a number of unresolved issues, two sets of considerations appear particularly relevant.

First, biotechnology innovations tend to be produced by private firms and to be protected by IPRs. Private Research and Development (R&D) is gaining increasing importance in agriculture, overturning the once dominant position of public R&D. The pricing of the resulting proprietary innovations will necessarily reflect the particular market power that an innovator can exploit. By impacting the pricing and adoption of innovations, IPRs affect the size and distribution of benefits from innovations. Consumers gain less from the introduction of a particular innovation (relative to it being competitively supplied), and farmers' welfare change is also reduced (but because farmers' net benefit could go either way under competitive pricing of the innovation, the impact of IPR pricing per se is ambiguous). Innovators can now directly capture a larger share of the benefits, and a direct consideration of the "innovation industry" turns out to be crucial for the proper assessment of the net benefits from biotechnology.

Second, there is the issue of consumer acceptance of biotechnology innovations, the regulatory responses that are likely induced by these innovations, and, more generally, the evolving market and institutional setting where these innovations take place. Whereas potentially large societal benefits are possible with biotechnology, they may not be realized, or they may be realized only at a large cost to a sizable part of society.

The conceptual model necessary for an assessment of biotechnology's economic benefits and costs is outlined, emphasizing the need to account for the proprietary nature of biotechnology innovations. The model is illustrated with an application to Roundup Ready soybeans. The estimated value of this innovation is sizeable, with consumers and innovators claiming the larger share of net benefits. Also, disparities in intellectual property rights (IPR) protection across countries affect the distribution of benefits. Consumer resistance toward genetically modified organisms (GMOs) and the issues of labeling and market segregation complicate the economic evaluation of biotechnology innovations, and a number of related regulation and public policy issues are discussed. Emerging output-trait GMOs are potentially less controversial and may bring more benefits to all participants in the agri-food sector, but this outcome depends crucially on the development of an effective, credible, and internationally harmonized regulatory system.

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