Journal of the Minnesota Academy of Science

Volume 53 | Number 1 Article 13

1987

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Introduction

The "green revolution" was used to characterize some of the significant increases in worldwide productivity that took place in agriculture during the last couple of decades. The remainder of this century will be a period of numerous changes in agriculture, some of which will be characterized as agriculture's "gene revolution." This revolution will have major impacts upon the plants, animals, and microbes that are important to the production and processing of agricultural products into food and nonfood products. These agricultural impacts will be made possible or accelerated by using the tools of biotechnology to alter the biology of these organisms in order to improve production efficiency, protect the environment, improve nutritional quality, or provide alternatives for processes or products.

Many of the previous increases in plant and animal productivity have been achieved through genetic improvement or management techniques that influenced traits such as disease resistance, increased growth rate, environmental adaptation, etc. Biotechnology offers not only the potential to accelerate some of these improvements within a species, but to potentially transfer desirable characteristics from one species to another. For example, insect resistance has been transferred from one species to another, an accomplishment that could not be readily achieved with more traditional techniques. Thus, the potential for improving commercially important plants, animals, and microorganisms is enormous. In fact, one of the major limitations at the present time is understanding the biology of these organisms to the extent of knowing which genes are responsible for specific traits. In this regard, the tools of biotechnology are driving science to a more complete biological understanding of these organisms. Without this basic biological understanding of the genes and their control, the tools of biotechnology cannot be fully used to improve the organisms.

Areas of Potential Impact

The following examples highlight the wide variety of changes that are reasonably possible. In some cases, the result has already been achieved or is near completion. However, even if achieved in the laboratory, the genetically modified organism must also satisfy the necessary regulatory requirements before adoption for general use.

Diagnostics

The production of highly specific monoclonal antibodies has revolutionized the accuracy, cost, and time necessary for the detection of many pathogenic or harmful organisms and residues in plants, animals, and food products. In addition, these tests are frequently much more sensitive than conventional techniques. This technology will be used to improve the safety of food products and in routine monitoring of the health of plants and animals.

Plants

The modification of economically important plants is essential for improved efficiency of production, reduction of chemical inputs such as fertilizers and pesticides, and the adaptation of plants to less favorable environmental conditions. The following are examples of areas where biotechnology is having or will have an impact on plant improvement:

- Genetic resistance to diseases, insects, and herbicides, which will not only reduce costly economic losses but reduce the cost of inputs now used to control insects, diseases, and weeds
- Improved use of nutrients such as nitrogen through enhancing or transferring the mechanisms that capture nitrogen from the air
- Increased resistance to stresses such as drought, cold temperatures, salt, or other toxic minerals such as aluminum
- Improved product quality through changes in such factors as amino acid profiles, flavor, texture, and ability of the product to maintain quality while in storage
- Improved yields through changes in the biology of the plant that affect such factors as photosynthesis, flowering and seed set, and the partioning of nutrients between grain and stalk

Animals

In general, livestock are more adaptable to a wider range of environmental conditions than specific plants, but like plants their productive efficiency is also decreased by diseases, insect pests, and the quantity and quality of available nutrients. In addition, the quality of animal products used for food is of concern because of their generally favorable nutrient profiles but highly perishable nature. The following are examples of areas where biotechnology is having or will have an impact upon animal agriculture and the products from it:

- Increased efficiency of production through changes in the biology that partions nutrients between body maintenance and such functions as reproduction, growth, and lactation
- Improved efficiency in converting feed nutrients into muscle, milk, or egg proteins rather than fat

- Improved resistance to diseases and insect pests (In the United States alone, the annual loss from infectious diseases of livestock is estimated to exceed $2 billion)
- Enhanced production efficiencies through sexing semen, embryo splitting, improved embryo survival, and more frequent twinning in cattle
- Improved digestion and use of feedstuffs through changes in the microorganisms of the digestive tract of the animal or through organisms that improve the breakdown of feedstuffs during fermentation processes

Microorganisms

Microorganisms are extremely important to agriculture. Their roles range from nitrogen fixation in leguminous plants to the breakdown of feedstuffs in ruminant animals such as cattle to fermentation processes that lead to cheese, sausage, and wine. In addition to their positive attributes, microorganisms are also the cause of some plant and animal diseases. The tools of biotechnology have been widely used on microorganisms. This use will continue, with many of the applications oriented toward food and agricultural issues. Some examples are as follows:

- Enhanced nitrogen fixation in legumes and eventually the transfer of this characteristic to plants that currently require nitrogen fertilizer
- Modification of microorganisms for use in the biological control of some insects, weeds, and diseases
- Improved strains of organisms to convert plant materials and biological wastes into better livestock feed, or into seedstock for the manufacture of chemicals or the production of essential nutrients such as vitamins and amino acids
- Improved strains of organisms for the production of new foods or food flavors, or for the improvement of present foods, such as the reduction of cholesterol in animal products

These examples for diagnostics, plants, animals, and microorganisms represent only a few of the potential applications of biotechnology to agricultural needs. Many of these are well along in development and others are already in use. During the next 5-15 years there will be many more. The rate at which these developments come about will be dependent upon the resources devoted to such biological research and the policies that regulate the testing and approval for use.

Minnesota and the United States must have policies that are appropriate to provide for safe use, but the policies must not be so restrictive that no incentive exists to try to capitalize on appropriate opportunities. There is a significant risk that overly restrictive policies will decrease the competitiveness of U.S. agriculture since this technology can be put in use in other countries. However, there is also a need to have reasonable assurance that products or organisms are safe before they are released for general use. These issues must involve multidisciplinary teams of scientists, informed and concerned citizens, as well as informed policy analysts and legislators. The criteria for evaluation should be science-based rather than based upon political concerns. Thus, more emphasis on science and policy information is needed in our educational programs and mass media communications.

It should also be obvious that biotechnology will have an impact upon farming practices. There will be increased use of improved plants and animals, biological control of pests such as weeds and insects, as well as improved conversion of biological materials into feed, food, and chemical seedstocks. These biological improvements coupled with changes in farm management practices and a reduced need for chemical inputs will probably increase the competitiveness of agriculture. At the same time there may be positive environmental impacts from permitting the removal of marginal land from production and reducing the use of some chemicals. In addition, many of the biotechnology advances in agriculture will have similar impacts upon different size farming operations. However, farmers that do not adapt and make use of cost-effective technologies will become increasingly less competitive.

Conclusion

Thus, the "gene revolution" for agriculture is upon us and it provides previously unimagined potential for modifying many biological processes important to agriculture and the environment. For this reason, one can predict that the next few decades will be one of the most important periods in agricultural history. Our success in capitalizing on the numerous opportunities will be dependent upon our investments in biological science that use biotechnology in both basic and applied dimensions to address agricultural issues, and the kinds of policies that regulate the use of these scientific developments. Agriculture is definitely entering an exciting new era, where the information age and the biological era are at least partially coincident. The history of agricultural development by the middle of the next century will include not only the mechanical age, the chemical era, and the information age, but also the biological or biotechnology era that is just beginning.

General References

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