BIOTECHNOLOGY FOR SUSTAINABLE AGRICULTURE

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ABSTRACT

Biotechnology can supply useful products for sustainable agriculture. The major contribution of biotechnology will be in reducing the use of agricultural chemicals, while sustaining the productivity needed to feed the world's population with more productive and resistant crops and animals, through faster and more precise diagnosis of plant and animal diseases, and through improvements in the supply of livestock feed.

INTRODUCTION

The continuing increase in the world's population, coupled with the limitations in the world's supply of natural resources and widespread degeneration of the environment, presents a major challenge to agricultural scientists today. Biotechnology may be able to provide an alternative to technologies that have harmful effects on the environment. Further, it has the potential of enhancing production on a sustainable basis, and, since it is flexible in its applications, can be adapted for both small-scale and large-scale operations (Fig. 1) (Padolina 1990).

CONSTRAINTS TO SUSTAINABLE PRODUCTION

Agricultural sustainability is the successful management of resources for agriculture to satisfy changing human needs, while maintaining or enhancing the quality of the environment and conserving natural resources (Gregory 1989).

Sustainable production is hampered by the decline in land and soil productivity as a result of inappropriate soil and water management practices. Furthermore, hazardous chemicals (pesticides and fungicides) are constantly being released into the environment, and are becoming increasingly toxic to human and animal life (Gregory 1989).

In many instances, the achievement of sustainability requires the use of purchased inputs such as improved seeds, chemical fertilizers, pesticides, tools and machinery (Gregory 1989). These requirements currently command high prices, making them unavailable to resource-poor farmers.

APPLICATIONS OF BIOTECHNOLOGY

One of the definitions of biotechnology is that it represents the application of biochemistry, biology, microbiology and chemical engineering to industrial processes and products (including the products used in health care, for energy and in agriculture) (Bull *et al.* 1982).

There are a number of reasons for considering biotechnology as appropriate for developing countries, most of which are in the tropical zone.

- Agriculture in tropical countries produces a considerable amount of crop residues and other biomass which offer opportunities for conversion into beneficial products;
- Biotechnology makes use of techniques which are relatively simple, perhaps because it deals with pre-existing, already available living materials (such as microorganisms or living tissue). In fact, the concepts and basic practices of biotechnology date back hundreds or thousands of years, to the days when human beings first began consuming fermented products such as beer, wine, cheese and yoghurt;
- The technology lends itself to decentralized applications, and can therefore be used in rural industries (Venkataraman 1987).

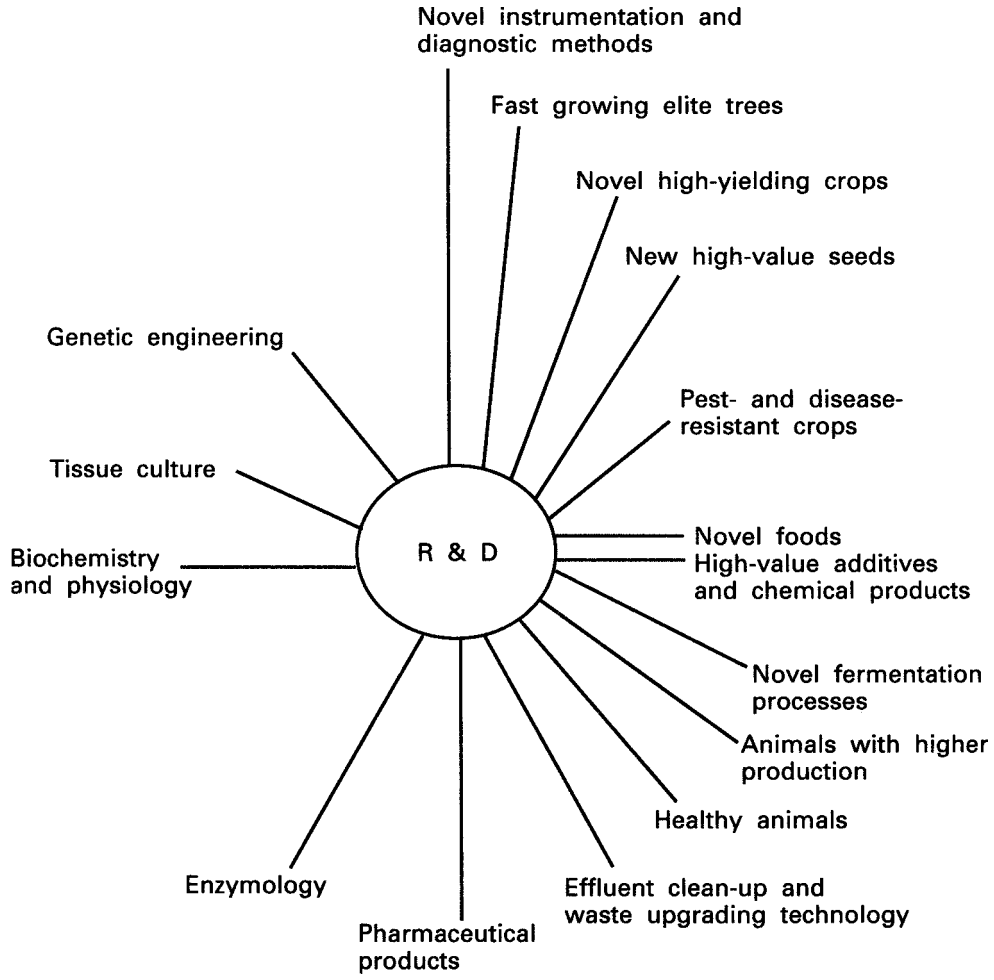

Fig. 1. Application of research and development in biotechnology

Source: Laboratory of the Government Chemist, U.K. 1986

Disease Control

In livestock production, biotechnology can provide genetically engineered animal vaccines, and large amounts of growth hormones from genetically engineered microorganisms. Other areas of interest are *in vitro* fertilization, artificial insemination and embryo transfer. Disease diagnosis in both plants and animals is being revolutionized through the development of DNA probes as well as antisera and monoclonal antibody (MAb) kits. With these tools, disease detection becomes more rapid and accurate, replacing the need to culture pathogens for identification.

Another related technology is the production of biocontrol agents with the potential to replace chemical pesticides. Although wild organisms may be used, as in the case of some *Bacillus thuringiensis* (Bt) - based insecticides, bacteria may also be manipulated in order to achieve a more potent formulation.

Although such products are at present still beyond the financial reach of most small-scale farmers, it is hoped that, when the techniques are further improved, such products will be available at a low cost for everyone's benefit.

ADVANCED BIOTECHNOLOGY

Recent research into biotechnology, particularly in developed countries, has focused on understanding the molecular basis of many bio-

chemical processes, and applying this knowledge to crop and animal improvement.

Modern biotechnology is still relatively expensive, and it may take years to fully develop a product, and even longer to put this product to practical use. The transfer of desired characteristics to plants and animals via genetic engineering is one way in which biotechnology will make a lasting impact. The process of trait transfer is faster, more precise and less likely to fail than conventional cross-breeding. Through genetic engineering, the nutritional content of plants can also be adjusted and pest- and disease-resistant crops can be produced. Furthermore, plants can be bred which can withstand drought, extreme heat or cold, or can thrive on salty soils, enabling farmers to utilize land that is currently useless.

Another useful tool is genetic mapping, using restriction fragment length polymorphism (RFLP). With this technique, traits otherwise difficult to screen can be easily and precisely recognized.

A less sophisticated technique which has already been practiced for a number of years is micropropagation. Plants are grown from single cells or from small pieces of plant tissue, thus allowing the rapid multiplication of identical plants of improved cultivars and pathogen-free planting stock. This method not only speeds up the breeding of improved cultivars but is a means of evaluating germplasm for various purposes (Espiritu 1990).

Biotechnology in developing countries, even without the use of expensive, sophisticated equipment, is yielding results with a wide range of potential applications and benefits (Table 1) (Espiritu 1990).

TRADITIONAL BIOTECHNOLOGY

While advanced techniques of biotechnology, in particular the genetic engineering of plants, animals and microorganisms and the use of DNA probes, is still mainly being carried out in developed countries, traditional biotechnology can be harnessed fully in developing countries.

Developing countries with their agricultural economies need to improve their agricultural practices to optimize their efficiency. There is a growing consensus that the basic aim of agricultural development is not only improved production, but an equitable, efficient and ecologically sustainable system of agriculture.

Biofertilizers

The use of biofertilizers is currently gaining interest as a cheap, safe alternative to conventional chemical fertilizers. *Rhizobium* technology, for example, reduces the need for chemical fertilizers and thus conserves energy resources (Paterno and Torres 1989). A legume inoculant (Nitro Plus) developed at the National Institutes of Biotechnology and Applied Microbiology (BIOTECH), University of the Philippines at Los Baños (UPLB), is now available for soybean, mungbean, cowpea and peanut. It is environmentally safe, and produces yields comparable with those obtained if inorganic fertilizer is used.

Mycorrhizal technology has likewise made possible the production of inoculants to significantly improve the survival, growth and establishment of trees and crops. Mycorrhiza are fungi symbiotically associated with plant roots. There are two types- ectomycorrhiza and endomycorrhiza. Ectomycorrhiza are found in association with forest trees such as pines, eucalyptus and dipterocarps, while endomycorrhizal associations are formed in horticultural, forest and agronomic crops (Aggangan 1989).

BIOTECH has produced inoculants for forest trees (ecto- and endomycorrhiza) and agricultural crops (endomycorrhiza). Seedlings in the nursery are inoculated with 'Mycogroe', the commercial name for the ectomycorrhizal inoculant. Endomycorrhiza are made into two products. Mycovam I, a soil inoculant, contains spores and infected root propagules of vesicular arbuscular mycorrhizal (VAM) fungi, while Mycovam II is a granulated form of the VAM inoculant. Both are effective for upland crops such as upland rice, corn, pineapple, sugarcane, peanut, soybean, mungbean, tomato and eggplant; orchard crops such as citrus, guava, soursop, and jackfruit; and tree species used for reforestation.

Another BIOTECH product is a bacterium-based fertilizer substitute. Inoculating corn with the microorganism *Azospirillum*, isolated from the roots of a pernicious weed, *Saccharum spontaneum*, reduces the plant's required nitrogen fertilizer input by up to two-thirds. Since the preparation is much cheaper than the fertilizer it replaces, it is of great benefit to corn producers, particularly subsistence farmers.

BIOTECH has also developed products to

Table 1. Products from low- to medium-level biotechnology successfully developed in the Third World

Technology group	Biotechnology product/process	Country where developed	Features
Livestock rearing	Mini-cow	Mexico	Mini-cow stands 2ft. high and weighs 200 kg., gives 1 gal. of milk/day; could be raised in 1/10 ha.
Tissue culture	Propagation of bananas and coconuts	Taiwan, Philippines	Enables the production of large numbers of uniform and high-yielding plants
	Propagation of mushrooms	Thailand, Philippines	Export crop, enhanced protein content for local diet
	New varieties of orchids and propagation	Thailand, Philippines, Singapore	Quick reproduction of orchids on large scale, export item
Biofertilizer	Biological N fixation using algae	Mainland China, Vietnam	Improvement of mass production of algae
Food processing	Rennin-like enzyme from fungi	Egypt	Serves as substitute for rennin used to coagulate milk protein in cheese-making
Pharmaceutical	Vaccine to control Hepatitis B	Philippines	Significantly reduces cost of Hepatitis B vaccine
	Vaccine against meningitis	Cuba	Important in controlling a serious disease in Cuba

Source: Clemente 1987

accelerate the conversion of large amounts of farm wastes into biofertilizers, using a combination of cellulose degraders and nitrogen fixers. This technology, which is both low-cost and effective, uses a commercially manufactured, low-cost composter. Simple bio-organic fertilizer plants can be established by small entrepreneurs to supply the fertilizer needs of nearby areas.

Treatment of Residues for Livestock Feed

Treated crop residues can be used, not only for organic fertilizers, but also for livestock feed. This not only gives the farmer a regular supply of low-cost feed, but also eliminates problems of agricultural waste disposal. Microbial treatment of carbohydrate-rich agricultural crop residues for animal feeds can be carried out at a farm level. Inoculants for different substrates will soon be available, and farmers will be able to apply the procedure without any need for costly equipment. The treated materials have been shown to possess improved digestibility and protein content, as in the case of the treated copra meal and cassava peels described by Teves *et al.* (1989) and Pham (1991), respectively.

The technique of making grass into ensilage as a high-quality livestock feed can be extended to include various agricultural wastes. Effective inoculants for such materials can be developed and made available for rural application.

Other Applications

Another practice which aims at making more efficient use of agricultural wastes is mushroom growing. This not only provides an additional food supply for rural families, but generates additional income for farmers.

Biogas technology likewise offers a solution to energy and environmental pollution problems. In addition, the sludge after processing can be applied as organic fertilizer. Biogas provides household cooking fuel and lighting in rural areas in a number of developing countries, and small factories in India and Nepal produce burners and mantle lamps for biogas fuel. Farmers in Mainland China and Taiwan ROC use sludge as fertilizer (Obias 1990).

The production of feed additives (eg. amino acids and antibiotics) is another area of biotechnology which can be successfully utilized in developing countries. Native isolates may be used, and simple equipment can be manufactured locally in order to reduce production costs. This will further reduce the dependence of developing countries on imports of expensive but essential commodities.

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DISCUSSION

In the discussion following the paper, participants expressed their interest in the inoculants for legume crops and forest trees described by Dr. Dalmacio, and the bacterium-based fertilizer substitute made from the microorganism *Azospirillum*. Dr. Hsieh was interested in the *Rhizobium* strains used for the legume inoculant, and asked how the strain had been produced. Dr. Dalmacio replied that it had been selected from a large number of strains collected in the field, but had not been genetically manipulated. The inoculum was mass produced in the Philippines in a fermentor, and packaged and sold commercially. It had a shelf life of six months at room temperature. Her laboratory was now working on the genetic improvement of the *Rhizobium* strain to give better nitrogen fixing ability. Dr. J.W. Hong pointed out that while *Rhizobium* and mycorrhiza gave the plant the ability to make more efficient use of nitrogen in the soil, it did not increase the nutrient content of the soil. Mycorrhiza were thus efficient in mining plant nutrients, but did not create any. Dr. Dalmacio felt it was still useful, when used with other techniques in a holistic approach.

Dr. Hsieh also asked whether biotechnology could overcome the difficulty described by Dr. Kim in the previous paper of giving good grain quality to varieties which were already efficient users of soil nitrogen. Dr. Dalmacio replied that biotechnology should be able to define the section of the chromosomes which give the characteristics desired by the plant breeder, and this would put breeders in a better position to judge the ability of a new variety.

Dr. Umali pointed out that biotechnology is creating products which are substitutes for agricultural products, such as the synthetic sugar which is now damaging the sugar export market of the Philippines. Dr. Dalmacio agreed that biotechnology should not be used to replace commodities exported from developing countries, but felt that it could give small-scale farmers a higher income when used for example to produce mushrooms or biofertilizer. Dr. Hamada was interested in the microbial treatment of carbohydrate-rich crop residues for animal feeds described by Dr. Dalmacio, and asked whether this had been extended to farmers. Dr. Dalmacio replied that the technology was still at the testing stage, but results were promising. Some microbes were able to degrade crop by-products and raise their nitrogen content by a significant amount, and the material processed in this way was then fed to poultry. Peels of banana and cassava, and also copra, were some of the products now being tested.