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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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THE PROMISE OF BIOTECHNOLOGY AND GENETIC ENGINEERING FOR AFRICA*

Prepared by

the

UNIDO secretariat

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The Promise of Biotechnology and Genetic Engineering for Africa

1. Introduction

The Lagos Plan of Action emphasizes using science and technology as tools for sustained economic development. Highest priority in the process of development is for African nations to achieve self-sufficiency in food production; second highest is to build up the industrial sector. The Lagos Plan of Action led to the programme called the Industrial Development Decade for Africa wherein a common framework is provided for guiding African countries in formulating development programmes and priorities within the context of individual countries development plans. At this meeting a next step is being considered, namely the implications of technological advances for African development. As was mentioned in the UNIDO paper "Technological Advances: Potentials and Implications for Africa" presented at the plenary session, biotechnology and its advanced techniques, including genetic engineering, is unquestionably one of the major technological advances of the present day and its importance is likely to grow. If fact, Nobelist A. Salam has suggested that the 21st century is likely to be the age of biotechnology. If this is so, the impacts of biotechnology are likely to affect most spheres of human endeavour, including these pertaining to food and industry. The question then is, what are the promises of biotechnology and genetic engineering for Africa and how may these promises be realized?

2. Biotechnology and Genetic Engineering

Biotechnology is defined as "the application of scientific and

engineering principles to the processing of materials by biological agents to provide goods and services" (1). The earliest applications of biotechnology was in the production of food and beverages; wine and beer maybe the oldest bio-products followed closely by cheese, yoghurt and baker's yeast. Industrial use of fermentation started in the early 1900s when bulk chemicals including acetone, butanol and ethanol were produced on a large scale. During the Second World War sophisticated fermentation techniques made possible the large-scale production of penicillin, followed by other antibiotics. After the Second World War, further development led to the production of what have until then been rare substances such as steroids, enzymes and certain vitamins.

In the early 1970s, techniques were developed that came to revolutionize biotechnology. It began when the future Nobelist Paul Berg of Stanford University embarked on a new line of research involving animal tumour viruses which was to lead to the development of a major technique of genetic engineering called recombinant DNA (rDNA) research (2). Recombinant DNA research involves the transfer of genetic material, usually one or more genes, from one organism (the donor) to a second (the host) where they are incorporated, or recombined, into the host's genetic structure. The host is usually a bacterium or a yeast. If all goes well, the recombined genes will perform the same function in the new host as they did in the donor organism. For example, the production in man of the protein human growth hormone (HGH) is coded for by specific genes. In 1978 scientists were able to insert these genes into the bacterium Escherichia coli (E. coli), thereby enabling it to produce HGH. This process is so successful that sufficiently large quantities of HGH is being made available to treat all persons suffering from dwarfism. Similarly, the new technique has enabled biological production to augment or replace the traditional means of chemical synthesis or extraction for several important substances used in medicine including human insulin and the anti-viral substance interferon.

Another technique of genetic engineering is based on the body's ability to produce antibodies against invading substances (commonly called antigens). An antigen can theoretically be almost anything: a

bacterium, a virus, a chemical and so on. The antibody produced is highly specific for the stimulating antigen. Before recent advances, antibodies could only be obtained from the blood of animals after a lengthy and expensive process. However, in 1975 C. Milstein and G. Kohler working in the United Kingdom were able to fuse a cell which produces an antibody but will not grow in a tissue culture with another cell which grows well in the laboratory (3). Afterwards, the hybrid cell (hybridoma) was able to divide and multiply to give rise to clones (identical daughter cells) which produce the required antibody (the monoclonal antibody or MCA). MCAs can be useful to detect minute quantities of almost any substance, but so far their main use is to detect antibodies which indicate the presence of disease, thereby enabling doctors to diagnose diseases much earlier than previously possible. In the near future, MCAs will be used to detect pollutants in water and air, to transport anti-cancer medication to specific cancer sites and, in industry, to separate out valuable substances from large quantities of reaction mixture and to purify them.

Though the first benefits from the new techniques will affect human and veterinary medicine, many feel the more important applications will be in the areas of energy, mining and agriculture (see table 1). For example, in energy new strains of microorganisms will more efficiently convert earth's most abundant resource, biomass, into primary energy substances such as biogas and alcohols. In mining, hardy strains will leach out large quantities of copper and uranium from now discarded mine tailings and from low quality areas. In agriculture, genetic engineering will be used within 10 years to improve crop strains and within 20 years it is likely plants will be fixing their own nitrogen (converting atmospheric nitrogen into easily assimilated plant nutrients), thereby lessening the need for artificial fertilizer.

3. Biotechnology and Developing Countries.

As it became imminent that industrial processes and products would emanate from the applications of genetic engineering, there were those who began to consider how biotechnology could help developing

countries. For example, UNIDO's Executive Director Dr. Abd-El Rahman Khane in a 1981 speech suggested that biotechnology "... could galvanize and broad-base the industrial structure of developing countries and impart new directions to industry, agriculture and energy" (4).

In order to explore the implications which biotechnology has for the developing nations, UNIDO invited a number of leading scientists and technologists to a meeting in February 1981. Their conclusion was that biotechnology offers opportunities for developing countries to solve inexpensively some of their pressing problems related to control of disease, shortage of food, and shortfalls of energy (5). In particular, the experts pointed out that the new genetic technologies will have a major commercial impact on the pharmaceutical, chemical and food industries, as well as on agriculture, probably in that order.

a) Pharmaceutical industry: At present biological methods are responsible for the production of about 20 per cent of all prescription drugs. The new genetic techniques will enable biological production to replace chemical synthesis, or extraction from animal and plant tissues, for many products. Already human insulin, growth hormone and interferons are produced by genetically engineered microorganisms. Soon the new technologies will open up possibilities for developing vaccines against such intractable diseases as hepatitis, malaria and schistosomiasis. In the next 10 to 20 years unique pharmaceuticals will be designated and produced, including new antibiotics, enzymes and hormones.

b) Chemical industry: 90 per cent of the substrates used to synthesize chemicals are petroleum based. Biotechnology can be profitably adopted to replace chemical synthesis because it will use renewable resources such as biomass instead of petroleum; the reactions occur at lower temperatures and pressures, thus saving energy; and there is less toxic pollution generated. Genetically engineered organisms are already producing valuable amino

acids for use as feed additives in animal husbandry. Other microorganisms are used to enhance oil recovery from exhausted wells, to destroy man-made pollutants such as DDT and to produce primary energy substances, including methane and alcohols from agricultural and industrial wastes.

c) Food industry: Genetically engineered organisms will soon be mass producing flavour enhancers and sweetening agents which are safe and nutritious. Others will turn inedible biomass into valuable food for man and feed stuff for animals. Large quantities of protein will become available cheeply through the production of single cell protein.

d) Agriculture: Since plants are extremely complex organisms (genetically speaking), advances will come more slowly. In 10 to 20 years plants will be genetically engineered to be resistant to disease, be able to survive stress brought about by drought or high saline soils and be made to tolerate high concentrations of herbicides and pesticides. In the longer term, agriculturally important plants may need less fertilizer as they are imbued with the ability to fix their own nitrogen from the air.

Before developing countries could undertake such far-reaching projects as here described it was clear that their capabilities had to be built up so their researchers will be able to perform advanced R&D and their industrialists be able to capitalize on the results therefrom. Accordingly, within UNIDO the idea developed that a useful mechanism for building up the capability of developing countries would be to set up an international centre where researchers from these countries would be trained and, concomitantly, where high quality research of direct pertinence to the developing countries would be performed. This idea quickly gained ground among scientists and policy makers in both developed and developing countries and as a result of this enthusiasm and much hard preparatory work, the International Centre for Genetic

Engineering and Biotechnology (ICGEB) became a reality when 26 countries signed its statutes at a Ministerial Level Meeting held at Madrid, 7-13 September 1983. Subsequently, on 4 April 1984, the ICGEB member countries decided that the Centre would consist of two equal components; one located in Trieste, Italy and the other in New Delhi, India. At the present time a Preparatory Committee, consisting of all ICGEB member countries, is working to make the Centre operational as soon as possible. As it now looks, research in temporary facilities will commence at both sites in the spring of 1985 and the first group of trainees will begin their training shortly afterwards.

The process of establishing the ICGEB has also had the significant effect of stimulating activities in a number of developing countries. An important feature of the ICGEB is that it will interact closely with affiliated regional and national centres and networks. Several countries have expressed interest in having affiliated centres. It is thus expected to become a focal point of world-wide activity in the field of genetic engineering and biotechnology. By this date, 35 countries belong to the ICGEB, including 10 African countries (see Table 2). Several of the African members have indicated their interest in establishing ICGEB affiliated centres.

4. Biotechnology in Africa.

In the UNIDO paper "Technological Advances: Potentials and Implications for Africa" considerable space is devoted to discussing a biomass-based strategy as an alternative pathway for industrialization. Here, in view of the high priorities given in the Lagos Plan to achieving self-sufficiency in food, consideration will be given to the possible applications of biotechnology and genetic engineering to this area.

M.S. Swaminathan has suggested that biotechnology will have its greatest impact on agriculture: "a major agricultural asset of many developing countries is the vast, untapped production reservoir arising from the prevailing gap between potential and actual yields even at current levels of technology" (6). The possibilities which biotechnology

offers to agriculture have been thoroughly discussed in at least two previous UNIDO documents (7, 8). For illustration, agriculture is here divided into two parts - animal husbandry and plant agriculture.

(i) Biotechnology and Animal Husbandry.

Productivity in animal husbandry can be raised by two methods; decreasing the loss of animals due to disease, and improving the genetic composition of animals.

Prevention and Control of Animal Disease.

Direct prevention and control of animal diseases is best accomplished through the use of appropriate vaccines. The theory behind vaccine R&D and production, as well as the application of biotechnology techniques to vaccine production, can here be discussed only briefly.

When a foreign body is introduced into an animal's body, the victim's immunological defense system reacts in several ways to neutralize the invader. If the invader is a microorganism, the victim's immune system can produce antibodies against different chemical structures which constitute the microorganism, such as the surface proteins. The chemical structures eliciting an antibody response are called antigens. In an immune host, the antibodies attach to the antigens located on the invaders's surface, thereby making it impossible for the invader to attach itself to the victim's tissue cells. Without the ability for attachment the invader cannot cause disease.

Vaccines are used for active immunization. These work by stimulating the recipient's immune system to produce antibodies against an invader but without causing disease. Though the antibodies produced survive only a short time, the cells which made the antibodies, the so-called B-cells, in co-operation with so-called memory cells, retain the ability to quickly produce the same type of antibodies for a future time when the host is again attacked. This ability confers immunity on the host which can last from months to years to a lifetime, depending on the quality of the antigenic response.

Vaccines produced through the use of "classical" techniques commonly fall into one of two categories. First, a pathogenic organism can be grown in large quantities, then inactivated or killed by heat or chemicals. When injected into a recipient, the inactivated form stimulates antibody production without causing disease. A second approach is to weaken (or attenuate) a pathogenic organism by breeding it in the laboratory for numerous generations, thereby making it impossible for the organism to revert to its original virulent form. The attenuated live organism, when injected into a host, will stimulate antibody production without causing harm.

The new biotechnology techniques greatly extend the possibilities for the manufacture of safe and efficient vaccines. The following methods are samples of these possibilities:

1. Recombinant DNA techniques can be used to "snip" out the disease-producing genes from a pathogenic agent. After this has been done, the organism will in effect be attenuated and can be used as a live vaccine.

2. It is possible to identify those antigens of a microbe which are important in its pathogenicity (the so-called "protective antigens"). The genes coding for the production of these proteins can be inserted and cloned in E. coli thus making available large quantities of the desired protein. The protein, when injected into a host, acts as an antigen thereby stimulating antibody production.

3. Many bacterial species have protrusions on their surface called pili. Pili aid the organism to adhere to tissue cells. Pili can be extracted from a bacterial culture and can be used as an antigen in the manufacture of vaccine.

4. With the help of computers, it is possible to determine the chemical make-up and structure of antigens. Based on this information, it is possible to synthesize antigens in the laboratory and to use them as a basis for vaccine.

5. Genes coding for antigens can be removed from a pathogen and be inserted into a known non-pathogenic organism. When injected as a vaccine, the recipient's immune system forms antibodies against the non-pathogen and, at the same time, other antibodies will be formed against the foreign antigen coded for by the inserted genes. In particular, researchers have found live vaccinia virus (used in smallpox vaccines) a suitable host for foreign genes from pathogens. Further, the vaccinia virus allows for the combining within itself of as many as six different viral genes, thus offering the possibility of vaccination against up to six diseases at one shot (9).

Most animal diseases are not reportable, therefore, it is difficult to estimate their incidence rates. Nevertheless, the loss due to animal disease is very large, an estimated US $50 billion world-wide (10). The animal vaccine market is also large, an estimated US $1 billion in 1981 and the market is estimated to grow 20-25 per cent per year between 1981-1985 (11).

In addition, the presence of infectious disease may cause serious but indirect losses, difficult to calculate. If diseases could be controlled, it is likely a substantial increase in animal supply would result. For example, bovine trypanosomiasis has been described "... economically as the most important disease of cattle on the African continent" and "... a major constraint to agricultural and socio-economic development in vast areas of Africa" (12).

As was mentioned above, it is possible to produce vaccines and sera against viruses, bacteria and parasites (such as protozoa) which are responsible for causing animal diseases.

Vaccines against viruses are the easiest to produce and are, therefore, the first to have been researched. Examples include:

a) Foot and Mouth Disease (FMD). This disease is a highly contagious, severely debilitating virus infection which

affects cloven-hoofed animals. Since the 1960s, a killed virus vaccine has been available but, on occasion, it has been found unsafe, it is unstable and it does not confer long-lasting immunity. Despite these problems, in Europe more than one billion doses of FMD vaccine are sold per year at an estimated cost of US $200 million (13). The disease is endemic in South America, Africa, much of Asia and in some European countries. A genetically engineered FMD vaccine is now undergoing clinical trials.

b) Rabies: The rabies virus can attack most warm-blooded animals and is transmitted by the bite of an infected animal. The disease is prevalent in all temperate and tropical areas though the animal species most affected vary according to locale. Rabies is particularly costly to developing countries. For example, in South America damage to cattle from the bites of diseased vampire bats is estimated to cause a loss of US $29 million per year (14). Several institutions are working on a genetically engineered rabies vaccine.

c) Blue Tongue: The disease is caused by insect-tranmitted virus attacking mainly sheep; it is endemic in Africa and the USA. Researchers in Israel, South Africa and the USA are using genetic engineering techniques in an attempt to produce effective vaccines (15).

d) Other viruses: Other viral diseases are being investigated but vaccines may be far off. Significant diseases on which research is proceeding are Marek's disease, Newcastle disease, African swine fever, canine parvovirus infection, Rift Valley fever, pseudorabies and African horse sickness.

Bacteria are genetically quite a bit more complicated than viruses and the state of anti-bacterial vaccine R&D reflects this fact. At present only one vaccine has been produced against a bacterial disease,

namely scours: a neonatal calf diarrhoea caused by an enteropathogenic strain of E. coli. It is responsible for severe economic losses throughout the world.

Parasites are even more complicated than bacteria and, therefore, present difficult problems to researchers seeking to produce vaccines against them. One on-going project is aimed at producing a vaccine against canine filariasis. The research group has already produced an MCA filariasis detection kit and are producing MCAs against a variety of filaria antigens (16). Another project is underway aimed at producing vaccines against bovine and canine babesiosis. The first is of extreme economical importance; an estimated 500 million cattle throughout the world are endangered by the causative organism Babesia bovis. An expert has states that "Babesiosis is presently considered as one of the most important constraints in production of cattle in most regions with tropical and semi-tropical climates" (17). Scientists have isolated glycoproteins shed by the parasite when it enters the blood stream and these glycoproteins, when combined with the plant extract saponin, have proven to be the basis for an effective vaccine. The vaccine has passed first trials and field trials are now underway in Australia and Venezuela (18).

Improving the Genetic Composition in Animals.

Several breeding technologies are uses to improve the genetic composition of animals, including estrus synchronization, artificial insemination and embryo transfer. These technologies do not usually use new biotechnology techniques and are therefore outside the scope of this paper. However, recently an important development in cattle breeding using MCAs has been reported. A US firm has produced an MCA against a male determinant found in cattle and by using this MCA, the sex of a six-day old embryo can be determined (19). With the new technique it has become possible to selective implant female embryos into surrogate mothers; an important development for the dairy industry since a cow may be worth US $2,500 while a male calf is worth perhaps US $50. The application of this technique may also become important to developing countries. Dairy cows in developing countries typically produce approximately 1,360 kgs. of milk per year while the selectively bred US

cow produces approximately 7,270 kgs. of milk (19). The new technique will enable cattle breeders in developing countries to purchase frozen embryos from highly productive cows and implant them into locally bred surrogate mothers. As a result, the fetus will inherit much of the mothers' immunity to local diseases and therefore will have a better chance of adapting to the local environment after birth.

(ii) Biotechnology and Plant Agriculture.

Plant products constitute an estimated 93 per cent of the human diet; to satisfy human nutritional needs 3.75 billion tons of food were produced by the world's agriculture in 1980, of which 1.9 billion tons were edible dry matter (20). Agriculture is both the oldest and the largest of the world's industries and will remain so for the foreseeable future. Dramatic gains in agriculture have been made in the last three decades largely as a result of the intensified use of land, fertilizers and pesticides and by planting improved crops developed through a variety of breeding programmes. In the years ahead, applications of new biotechnology techniques are likely to allow the high growth rate to continue. Two broad avenues of biotechnology R&D will here be investigated; the genetic improvement of plants and the development of efficient non-chemical pesticides.

Genetic Improvements of Plants.

A recent study on applied genetics presents a three-phase programme of plant breeding which incorporates some of the new biotechnology techniques (21):

Phase I: Plant Cell Cultures.

The basis of this technique rests on the ability of researchers to regenerate plants from a mass of disorganized tissue called callus. In the 1960s it was demonstrated that a single cultured cell could divide and form calluses; a little later, researchers were able to grow a complete and fertile plant from a single isolated plant cell. At present, a large number of plants can be produced from a single callus. For example, one gram of starting carrot callus may produce 500 plants (20).

An important recent finding is that cells in a tissue culture, when allowed to develop into full plants, may differ markedly from one another though they all come from the same parent. This variation in cultured cells is called somoclonal varitation (22). The genetic variability can be used to select cells with desired characteristics by manipulating the media in which they grow. By using this approach it may, for example, be possible to select cells which exhibit marked tolerance to salts, metals, herbicides and extremes of soil acidity and alkalinity.

Phase II: Genetic Engineering.

Due to the limited knowledge of plant molecular biology, little has been accomplished as to inserting foreign genes into plant cells. The reason hinges on the complexity of plants' genetic make-up. Genes in higher organisms are generally clustered into units called chromosomes. Gene function might be dependent on several factors: the sequence of genes on the chromosome; their spatial relationship; the mechanisms which "turn" the genes on and off, etc. For the foreign gene to become functional in a plant it must be first inserted into the nucleus of the plant cell without damaging the cell or its parts and, second, the gene must be incorporated correctly in the chromosome and its control mechanisms made to function. This series of steps is difficult to accomplish. However, a start has been made - foreign genes have been inserted into plants.

Two separate groups, one in the US and the other in Belgium, announced results from their work in this area at the 15th Miami Winter Symposium, January 1983. Both groups used nearly the same methods and the same vectors for transferring foreign genes into a plant. It has been known for a long time that the bacterium Agrobacter tumefaciens can cause tumours in plants by infiltrating part of its own genes into plant cells. Researchers were able to remove a plasmid (genetic material which is not part of the bacterial chromosome) from the bacterium, cut out the genes that code for tumour formation and replace them with foreign genes coding for resistance to the antibiotic kanamycin. The engineered bacterium was subsequently able to infiltrate the foreign genes into a variety of plant cells, many of which were converted into healthy, intact plants highly resistant to kanamycin (23).

A promising line of research of potential importance to Africa is underway at Michigan State University. Researchers there have found that a single gene codes for resistance of weeds to the herbicide atrazine. They are now working on developing herbicide-resistant crop plants by inserting the resistance gene into a target plant either through protoplast fusion or by direct introduction of the cloned genes into plant chloroplasts (24).

Phase III: Plant Generation.

Severe problems have yet to be overcome in the regeneration of plant from single cells. The main problem is that the procedure has only been perfected in a few crops; the most important legume and grass crops have resisted regeneration efforts. Yet, a start has been made by two groups that succeeded in transferring the kanamycin-resistant gene to plant cells and subsequently were able to grow full plants from the engineered cells. The variety of plants grown included petunia, sunflower, tobacco and carrot.

A project of potential importance to the African agriculture is one being undertaken by Phytogen (USA) to produce improved cotton strains. Phytogen researchers are attempting to introduce a gene for herbicide resistance into cotton, preferably directly into the cotton callus (25). If this attempt is successful, stronger concentrations of herbicides could be used to control weed overgrowth.

To conclude this part on genetic improvement of plants, brief comments will be made in reference to a potentially extremely important research area Africa (though be it long-term); the incorporation of nitrogen fixation genes into plants.

Nitrogen is essential for both growth and propagation. However, it must be available in a form which plants can use. Commonly, this is in a form found in chemically synthesized fertilizers. Important cereal crops almost totally dependent on fertilizers are wheat, corn, rice and forage grasses. A few plant species have developed symbiotic relationships with microorganisms which have the ability to combine

atmospheric nitrogen with elements such as carbon, hydrogen, and oxygen to form nitrogenous compounds useable by the plant in a process called nitrogen fixation (Nif). The symbiotic relationship is best exemplified by that between legumes and the soil bacteria Rhizobium where the latter is encapsulated in nodules found at the legume's roots. Several species of free-living bacteria also have Nif ability including the ubiquitous Klebsiella pneumoniae. At least 17 genes are involved in its Nif process.

The world demand for chemical fertilizer was an estimated 51.4 million tons in 1979 but the demand will grow to between 144 and 180 million tons by 2000 (26). Nif organisms fix approximately 175 million tons per year and, of course, this quantity is not likely to increase unless new developments take place to increase plants' Nif capabilities.

Many research groups in both developed and developing countries are working on Nif. Efforts are underway to clarify the symbiotic relationships between plants and their Nif symbionts, to study the molecular regulation of Nif gene expression and to understand the energy requirements of the Nif process. Eventually scientists hope to increase the role of Nif microorganisms by one, or more, of the following accomplishments: by genetically manipulating existing Nif systems in order to increase their efficiency; by transferring the Nif gene complex from bacteria to plant so they can fix nitrogen directly from the air; and by growing large numbers of Nif microorganisms in fermenters and seeding them directly in the soil (soil inoculation).

The aim of Nif research is to allow farmers to lessen their dependence on chemical fertilizers. As energy costs have increased over the last decade, fertilizers have become excessively expensive thereby limiting their use in developing countries. And, in many cases, the unwise or uncontrolled use of fertilizers has damaged soils by making them salty and has led to pollution of lakes, rivers and other water-shed.

Biotechnology and Pesticides.

The use of chemical pesticides has been beneficial to the world's population because the protection they afford to animal husbandry and

plant agriculture has in part been responsible for the tremendous growth of agriculture in the last 30 years. At the same time, no one can ignore the largely unanticipated negative side effects that have accompanied pesticide use or that have become apparent with the passage of time. Biotechnology offers several means of overcoming deleterious side effects, most particularly by allowing farmers to adopt biological control agents.

Microorganisms that infect insects are called entomopathogens and include bacteria, viruses and fungi. The best known of the entomopathogens are bacteria of the genus Bacillus thuringiensis which have shown to be active against several insects. In particular, B. thuringiensis israelensis has a high degree of activity against mosquitoes and blackflies while B. thuringiensis Sp-24 is active against the cotton leaf worm. Bacillus acts by secreting a toxin which is a stomach poison to larvae.

A few companies began producing commercial quantities of B. thuringiensis after the product was found safe by WHO. The major shortcoming is its short residual effect, necessitating frequent reapplications (27). However, by using new biotechnology techniques these shortcomings can be overcome. Two R&D approaches are being taken: (1) investigations centering on the toxins of entomopathogens, and (2) the transfer of entomopathogenic activity from one organism to the other. Both approaches are in their formative stages, i.e., the work being done is basic research. Though the toxin coding genes have been identified, isolated and trasferred from B. thuringiensis to other organisms having industrial potential, it is too early to know whether the toxins under investigation can actually be used on large scale in the field. Complex questions need to be answered such as: what is the stability of the toxins in nature; what is their effectiveness; what are their long-term environmental effects, etc. Yet, it is clear that R&D undertaken in regard to entomopathogens has a good chance of achieving results in the short-term. However, applications may be futher off since products have to be tested and found safe to man and his environment. Endowing organisms now not considered to be entomopathogenic with such properties would pose an analogous situation; the safety and efficiency

of the newly engineered organism will have to be measured and assessed before large scale application is contemplated. Nevertheless, the opportunities for developing an industry in Africa based on entomopathogens should be seriously considered.

5. Discussion

Agriculture is the most important of human industrial activity since its products affect immediately and directly the well-being of all people. Sufficient food is today being produced to provide in theory each one of the Earth's population with 3,000 calories per day but as the rate of population growth is approximately 2 per cent, this satisfactory situation is bound to come to an end - by 2015 there will exist an estimated 8 billion people on Earth. Since the estimated 4 billion population in 1975 required 3.3 billion tons of food, 6.6 billion tons will be needed in 2015 (28). The increased demand can only be met by intensified production, by making new land available for farming and by developing new production possibilities, for example, in the marine environment.

The foregoing survey indicates that intensive activity is taking place related to increasing production in agriculture using new biotechnology techniques. Opportunities exist for R&D leading to short- and medium-term gains that can be profitably undertaken by researchers in African countries:

(i) Short Term

It is vital that African researchers become thoroughly familiar with tissue culture. This technology affords researchers the ability to subject plant cells to manipulative techniques such as mutation, strain selection and process development and to be able to review results rather quickly. When a successful strain is recognized the whole plant can be grown and, in turn, its tissue used to seed other tissue culture. One authority estimates that this cloning method is one million times faster

amortized. For example, in the USA a commercial nursery may invest US $50,000 to establish a tissue culture facility. This facility could breed a superior plant variety and produce 300,000 clones of this plant per month. Sale of clones would quickly pay off the initial investment (30).

Tissue culture technology can be particularly valuable to countries in the tropical regions that wish to exploit their botanical resources. The genetic variability in the form of germ cells or seeds (germplasm) offered by tropical forests and gardens present unending possibilities for utilization by agriculture. The unique genetic traits present in novel indigenous plants can be used to improve crop strains in all parts of the world. Wild species have been utilized by agronomists for many years as a necessary source of genetic variation for introducing pest and disease resistance to crop plants. An illuminating example is the incorporation of a gene coding for resistance to striped rust; a fungal disease which afflicts barley. A suitable gene was found in an Ethiopian barley species and through the use of advanced breeding techniques was incorporated into US barley varieties, thereby saving the US farmers approximately US $150 million per year (31).

An additional reason for undertaking R&D using the advanced breeding techniques is that it provides researchers with the tools to alleviate specific problems, such as plant disease, much faster than previously possibly. An example of how quickly agronomists can react to alleviate plant disease by using advanced plant breeding technologies is the effort, presently underway, to deal with the fungal disease orange leaf rust which threatens to destroy Mexico's major coffee-producing areas, endangering an export woth US $550 million per year. In response, a multi-national effort, utilizing the resources of Purdue University and the Coffee Rust Research Institute in Portugal, was started in 1983 primarily to develop a rust-resistant variety of coffee using tissue culture and other breeding techniques. Six month later newly installed greenhouses were ready to begin turning out 200,000 cloned, rust-resistant plants every three weeks (32).

Opportunities for research pertaining to plant disease are numerous,

for example, much can be done to develop palms resistant to the diseases cadang-cadang and root wilt; plants resistant to southern corn leaf blight; tobacco resistant to the bacterial disease wildfire, etc. Research pertaining to the transfer of genes between microorganisms and plants or from plant to plant is in its infancy. As mentioned only three sucessful attempts have been reported in the literature. However, the transfer or modification of single genes may offer short-term opportunities; for example, to incrementally improve steps in Nif or photosynthesis processes by replacing a gene coding for an enzyme with another coding for a more useful enzyme, and to alter the genetic code which controls amino acid synthesis in order to produce improved proteins.

Regeneration of whole plants from tissue cells is yet another fertile field of investigation with a short-term potential for pay-offs. An important limitation of this technique is that important crop plants have not been regenerated (including large-seeded legumes such as soy beens, beans and peas); neither have most forestry species (33). Researchers from developing countries may find it profitable to develop regeneration techniques for tropical plants now not being studied. If regeneration of an agriculturally important plant is accomplished, researchers may be able to employ selection techniques for follow-up work to select variants for possible use in crop improvement schemes, either at home or for export. For example, tropical countries may have unique plants and microorganisms that produce fragrance or aroma chemicals. Fragrance substances have a combined market value of approximately US $2 billion per year (34). By using traditional breeding technologies, tissue culturing, genetic engineering techniques and regeneration it is probable that the number of plants producing different odoriferous substances can be increased, that the variety of pleasant odours can be expanded, and the quality of some fragrances can be improved. The makers of cosmetics, toiletries and detergents are continually seeking new and exotic fragrances so a ready market exists for products from plants engineered to produce new, pleasant odoriferous substances.

It is difficult to enumerate the many existing research opportunities in agriculture which will utilize new biotechnology

those already discussed, the following possibilities using tissue culture and other plant breeding techniques may be mentioned (35):

a) At the cellular level, to select mutants of the rice plant with high tolerances for salt and aluminium;

b) To find and develop tobacco mutants having reduced photorespiration;

c) To produce rice strains with high lysine and high protein contents;

d) To develop rice strains resistant to sheath blight;

e) To solve rice plant regeneration problems.

Medium-Term Projects.

Large areas of previously fertile agricultural lands have in the last two decades been degraded due to increasing soil salinity. The mechanisms whereby microbial and plant cells adapt to the stress of increased salt in the environment (or osmotic stress) is osmoregulation. This field is now being intensively studied in developed countries and it has become clear the genetic engineering technologies will play a large part in adapting plants to osmotic stress (36). Due to the many facets of osmoregulation, R&D in this area demands an integrated, multidisciplinary approach. At the minimum, scientists familiar with genetic regulation and transfer, with enzyme systems, and with cellular membrane functions will have to make up research teams. For reasons such as this, if an African nation wishes to commence R&D in this area, it must be ready to make a major commitment in resources and time and not expect results leading to applications for at least five years.

The possibility of adapting Ti plasmids for use as vectors to carry foreign genes into plant has already been discussed. However, there

in this area is lacking. Therefore, scientists in African countries could be in a favourable position to investigate plant diseases peculiar to tropical and semi-tropical regions that are caused by disease agents having the potential as vectors. Possible disease agents now under investigation are the cauliflower mosaic virus (the causative agent for oleander knot) and various phages that afflict bacterial pathogens of plants.

Suggestions for developing plants resistant to diseases, antibiotics, pesticides and saline have been made earlier. It was pointed out that short-term results are most likely to occur when the factor to be modified is coded for by a single gene. It is more likely that most resistance factors are controlled by multi-genes and will, therefore, be difficult to undertake with results to be achieved in the long term. R&D related to plant resistance against diseases, alkaline earth, anaerobic soil conditions (as a result of flooding), drought and changes in soil pH fall into this category.

In passing, it should be noted that researchers in developing countries may be in a particularly good position to perform R&D related to resistance for the following reasons: much agriculture R&D in developed countries is funded by private industry or performed in industrial laboratories. This industry is largely made up of, or influenced by, giant chemical concerns and seed companies. Logically, it makes more commercial sense for these giants to develop better chemical agents to control plant disease and pest rather than invest in R&D leading to resistant plants. If this supposition is correct, it may be that R&D pertaining to plants resistance is underfunded, leaving a void that could be filled by researchers in developing countries.

To conclude the discussion on medium-term possibilities for the R&D in agriculture, a mention should be made of an US National Research Council recommendation pertaining to the use of MCAs in plant health (37). It was pointed out that limited means exist for identifying the large variety of pathogens causing disease among the world's important plant crops. Failure to identify disease agents has meant that their

diagnosed in a timely manner leading to wrong and/or late treatment with resultant crop losses. High priority should, therefore, be given to developing MCAs against the following disease agents:

a) Rice (rice dwarf, rice grassy stunt, rice ragged stunt, rice tungro);

b) Maize (maize chlorotic leaf spot, maize rough dwarf, maize streak);

c) Cassava (cassava mosaic virus);

d) Citrus (citrus tristeza virus, Spiroplasma citri, Xanthomonas citri);

e) Potato (potato viruses M, S, X, and Y; potato leaf roll);

f) Fruit trees (Prunus necrotic ring spot, apple mosaic, prune dwarf, tobacco streak, tomato ring spot, tobacco ring spot viruses).

6. Possible Actions.

As developing countries grow aware of the potential benefits of biotechnology, many of them are beginning to take steps which will allow their researchers to perform goal-directed R&D and their industrialists to capitalize on the results of both indigenous and foreign research. However, these efforts face severe constraints. The educational systems in the third world may not be geared for the education and training of the high quality, multidisciplinary researchers required in biotechnology. Many countries do not have either the adequate technological resources or the scientific competence to individually take up bioscience R&D or to develop scale-up and down-stream industrial processes. Capital investment funds for setting up a bioscience-based industry may be lacking and indirect constraints may act to discourage

Many of these constraints can be overcome or circumvented through international cooperative actions. National decision-makers can become informed about biotechnology through the informative programmes by UNIDO. Further, if assistance is required by countries to formulate national programmes or to establish national biotechnology centres, UNIDO can provide the requisite advisory services. UNIDO may provide help to draw up the appropriate industrial policy and to negotiate contracts for international biotechnology transfer.

In the medium-term, the ICGEB will positively affect the capability of developing country researchers and technologists to perform advanced biotechnology R&D to scale-up laboratory procedures and to undertake down-stream processing. This will be partially done by having the Centre's scientists perform important in-house research for developing countries, and partially by the ICGEB and its affiliated centres providing thorough training for a comparatively speaking large number of third world researchers. A primary objective is "... to give advanced training to individuals who have the potential to create innovative groups for industrial activity in the home country. This type of training should be such that it would open the road to a wide range of applications, and it definitely presupposes participating in active research processes".

The lack of resources prevents all international organizations from undertaking large, wide-ranging programmes to bring biotechnology and its benefits to the developing countries. Nevertheless, they can fulfill important roles by catalyzing projects that can have significant effects on the local level and they can provide timely, accurate advice to decision-makers not so knowledgeable about biotechnology or its scientific underpinnings. Within the context of this meeting, UNIDO presents two suggestions for action plans which would serve to help African countries build up their capabilities in biotechnology and genetic engineering.

A. Regional network for biotechnology in Africa.

It is proposed to establish and make operational a regional biotechnology network to serve the African region. It would link existing R&D centres in order to accomplish these major functions; they will perform in-house advanced biotechnology of pertinence to the region; they will train researchers from countries in the region in the advanced techniques of biotechnology such as genetic engineering; and they will act as focal points for the collection of scientific information and the further dissemination of the same to associated national R&D centres.

In order to begin this project, representatives from UNIDO would meet with African policy-makers and representatives from R&D institutions as well as officials from ECA and OAU in order to perform a survey of biotechnology research now underway in African countries and where it is performed, paying particular attention to scientific manpower resources, equipment, the extent of local support and finances and existing arrangements for collaboration. Selected institutions found to be the most appropriate for linkage via networking, will be visited by UNIDO missions. Based on the foregoing survey and evaluation of institutions, UNIDO staff with the help of short-term scientific/technical consultants will design an African biotechnology network. Upon completion, a description of the designed project will be issued to interested governments and R&D centres.

After the issuance of the project design a regional conference will be organized to which will be invited scientists, industrialists and decision-makers from African countries and internationally prominent biotechnologists. Using the project design as a basis for action, conference participants will decide on the work programme to be undertaker at the linked R&D centres as well as make decisions on the factors mentioned above. The regional network would then be established on the terms decided on by the participating countries and national R&D institutions.

B. To establish a regional coopera
in Africa in cooperation with E

It is only rarely that an Af
manpower or the specialized, fully e
carry out advanced biotechnology
approach is for several countries to
perform research of common intere
action for building up their base of

In order to quickly commence a
research and training and to ta
where notable research is already be
initially two existing facilities
to the extent they will be able
purposes and to train researchers
building up of capability in biote
envisaged additional national R&D
units in the cooperative research an
is also envisaged that this pro
proposed regional network for biotec

The overall purpose of capab
countries to achieve self-sufficie

tive research and training programme
CA and OAU.

rican country has either the scientific
quipped R&D facilities necessary to
research. Therefore, a reasonable
pool their resources in order to
est or necessity and to take common
scientific manpower.

regional programme for biotechnology
ke advantage of existing R&D facilities
ing performed, it is proposed that
be augmented through UNIDO intercession
to undertake research for regional
from countries in the region. With the
chnology by other countries, it is
centres will also become functional
i training programme for Africa. It
gramme become an integral part of the
nology in Africa (see above).

lity building is to allow African
ncy; a concept which means more than
nd to establish industry. It means
y over biotechnology, i.e., having
d the dynamics of the bioscience;
from research to reach practical goals
l being able to adapt and improve

TABLE 1

Postulated dates for the marketing of products developed as a result of genetic engineering applications:

1985	Interferons for use in cancer research (medicine)
1986	Interferons for use as antiviral agents (medicine)
1988	Clinical trial of Hepatitis B vaccine (medicine)
1989	Improved strains for the conversion of biomass into energy sources (energy)
1990	Improved strains for mining processes, especially to maximize copper and uranium recovery (mining industry)
1990	Large scale use of genetically engineered organisms to help control various pollutants (environmental science)
1995	Introduction of genetically improved plants in agriculture (agriculture)
2000	Introduction of plants capable of fixing nitrogen (agriculture)

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