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THE POTENTIAL FOR BIOTECHNOLOGY IN AFRICA[a]

by

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INTRODUCTION:

Africa is to-day faced with a food crisis which is the result of a number of contributory factors. According to the FAO, the total demand for food and related agricultural products in sub-Sahara Africa will grow at the rate of 3.5% annually, from now to the year 2000 (FAO, 1987). On the other hand, the sub-region's population is estimated to be growing at the rate of 3.3% per annum between 1985 and the year 2000 and would reach 675 million by then. It has also been discovered that food production in sub-Sahara African countries has either stagnated or has declined in the recent past, and that food supply problems are worsening (FAO, 1^91). These population pressures and poor food security are thus adding fuel to the embers of the food crisis. Another contributory factor to the food crisis is the poor management of Africa's natural resources. All the above problems have resulted in hunger, disease, energy shortages, environmental deterioration and pollution, and can only lead to unsustainable development.

Biotechnology, as a tool in science and technology development, is now recognized worldwide as one of the most important developments

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of the 20th century. This recognition is based on the recent advances in cellular and molecular biology which have provided novel avenues for genetic manipulation of micro-organisms, plants and animals, which lead to products of benefit to human kind directly or indirectly. Some of these include the production of food and fibre, other goods and services such as improved plants and their products, pharmaceuticals, vaccines, human and animal health, and the environment. Although the advancements in biotechnology and commercialization of their products were started mainly in the industrialized countries of Europe, United States of America, and Japan, their potential importance for solving most of the current chronic problems of developing countries has been realized (Anon, 1984; Anon, 1989).

PROS AND CONS FOR BIOTECHNOLOGY IN AFRICA:

Although the prospects for employing biotechnology for solving developmental problems in Africa are bright, several points have been made for and against the proposition. First, practically all the commercial applications of biotechnology have occurred in the developed countries, as stated above. Moreover, because of the long standing and well-established scientific base and excellent infrastructure in these countries, they are able to embark on very advanced biotechnology R&D. Besides, almost all the processes and products of biotechnology are under the control of the private sector in these countries which, in any case, already have strong economies, high living standards, and small populations. Biotechnology will therefore produce more wealth for them. Also, a substantial part of the biotechnology effort in these developed countries is directed towards crops, animals, diseases and other problems that are of particular interest to them. Some of the products include those that substitute for the raw exportable commodities from developing countries, thus making traditional food and cash crops from these countries redundant, and causing misery to farmers. These developments will therefore have a negative influence on many developing countries which, instead of benefitting, will be marginalized.

On the other hand advanced research in and commercialization of biotechnology are either non-existent or just beginning in developing countries of Africa, Asia, Latin America, and the Arab countries of the Middle East. These countries also suffer from large populations, and rapid population growth rates, low standards of living, poor health, many endemic diseases and weak economies. Thus, biotechnology would potentially bring dramatic benefits to these countries and their peoples. The most attractive way of realizing this potential is for the developing countries to acquire and develop expertise in biotechnology so as to be self-reliant, and find the solutions to their problems. In essence, the need is paramount for them to establish their own biotechnology research programmes, bearing in mind their own interests and priorities.

CAPACITY BUILDING AND ORDERING OF PRIORITIES:

Developing countries of Africa desirous to embark on biotechnology as a means of rapid development, must deliberately engage in capacity building in order to succeed (Okonkwo, 1990). Several areas merit attention as follows:

Awareness and planning:

It is important for African countries to be aware of the recent advances in biotechnology R&D in developed countries, the impact that biotechnology is having on their economies, and how the African countries' economies are likely to be affected. For instance, some commercialized products of biotechnology from developed countries may compete with or tend to displace some commercial items produced by developing countries, e.g. high fructose corn syrup (HFCS) displacing cane sugar, or starch-based gums displacing gum arabic, etc. Thus, each developing country in Africa must plan a programme for its biotechnology R&D activities against the background of adequate information. It may find alternative uses for some displaced items of commerce, or it may develop its own new items that are attractive to new markets.

Assessment:

Planning must include a critical appraisal of national needs and the importance of ordering priorities. In assessing the position on the ground, it is essential to survey, quantify and categorize the available trained scientific manpower, including scientists and technicians, to inform the kinds and levels of activities to start with. The information obtained would indicate in which direction and at what levels future training should be planned for, in order to provide the critical mass of high-level trained manpower for biotechnology R&D. It is also important in planning and assessment efforts, to provide adequate infrastructure for biotechnology R&D including laboratory space, equipment and supplies in Universities, Research Institutes, Colleges and Polytechnics, and in the private sector of the developing country, as well as to provide and maintain the utilities such as electricity supply, water and communication facilities.

BIOTECHNOLOGY R&D PRIORITIES FOR AFRICA:

African governments, aided by their scientists and friends, need to identify priority projects where biotechnology R&D can best provide solutions to problems, and yield socio-economic benefits in tangible time. Three areas seem attractive for such efforts, namely, Agriculture, Health and Industry.

AGRICULTURE:

Since food insecurity is at the root of Africa's problems, agriculture seems an area of high priority meriting initial vigorous attention. In this regard, efforts should be initiated in aspects which are easier to embark on to yield short-term benefits, and complement ongoing conventional agricultural practices. Other problems whose solutions require the use of more sophisticated facilities should be embarked on in time when the infrastructure improves. Areas of biotechnology that would help improve agricultural production include, plant biotechnology, microbial biotechnology, animal biotechnology and aquatic biotechnology.

1. Plant Biotechnology:

Plant biotechnology through the techniques of plant cell, tissue and organ culture holds great promise for achieving short-term benefits in agriculture without the demands of high sophistication in infrastructure and instrumentation. Examples of such applications are:

(a) Clonal propagation: Clonal propagation by cell and tissue culture, is a sure way of achieving mass and cheap propagation of elite crop cultivars for increased food supply (Vasil, 1986; Levin et al, 1988). The technique is also applicable to the mass propagation of forest tree species for afforestation programmes needed urgently to counter the evil ecological and environmental effects of indiscriminate destruction of forests, and to prevent desert encroachment.

(b) Meristem culture and disease elimination:

The growing shoot tips of plants consist of meristematic cells which are free of virus and other microbes. Thus, the culture of isolated meristems is a reliable means of eliminating these organisms and of producing disease-free planting stocks of crop plants which enhance agricultural productivity. Examples of crops which have been "cleaned" by this method are cassava, sweet potato, yam, cocoa, and strawberry (Anon, 1984).

(c) Embryo culture: Embryos from wide crosses involving plants from widely separated species, often abort due to cross-imcompatibilities. Such embryos may contain unique and useful combinations of genes that may be expressed as disease or other environmental stress resistance. By "rescuing" the embryos and culturing them *in vitro*, they can be saved and the beneficial traits realized.

(d) Pollen and anther culture for haploids:

In vitro culture of pollen, anthers and ovaries provides a rapid (weeks to a few months) and reliable method for the production of haploid (infertile) plants. The latter can be readily converted, by induced chromosome doubling, to yield diploid, fertile, homozygous plants which are important for developing new breeding lines, new cultivars, and hybrid vigour. Recessive genes which may code for some important characteristics are easily expressed in these lines. Conventional methods of producing homozygous pure breeding lines are extremely labour-intensive and time-consuming, often lasting for many years (Vasil and Nitsch, 1975; Heberle-Bors, 1985; Vasil, 1990).

(e) Germplasm conservation: Tissue culture procedures also provide a means for conserving genetic resources in the form of gene banks. *In vitro* cultures of accessions, especially those of endangered but valuable plant species, perpetuate these species, and facilitate international exchange of materials. The system also helps to maintain the unique plant diversity of Africa and to back-up other efforts in the application of this methodology for development.

(f) Resistance breeding: Cell and tissue culture methods enable breeding for stress tolerance such as drought, alkalinity, acidity, and salinity. This helps to bring into cultivation many African lands which have been marginalized by such stresses.

All the above biotechnological techniques and applications should be within the reach of African countries, as they do not require very sophisticated laboratory appliances. Thus, they can be applied in the rear- and mid-term for immediate or short-term benefits.

The following three areas of plant biotechnology require sophisticated and expensive laboratory facilities and specially trained scientists to engage in them. However, in view of the fact that they hold so much promise for improving agriculture and food security in the short term, they merit inclusion in an African plant biotechnology programme for rapid development. Special training of scientists and capacity building in these areas must be planned and mobilized by African countries desirous to tap these systems. These include genetic engineering for herbicide resistance, insect resistance, and virus tolerance.

(g) Genetic engineering for herbicide resistance: Weeds cause heavy losses in crops. Herbicides (weed killers) which are often used to eliminate the weeds are environmentally unsafe and their residues cause problems for animal life. New classes of herbicides such as glyphosate (Roundup) etc. are non-selective and kill all plants. However, these latter herbicides are rapidly biodegraded and thus do not contaminate underground water. Resistance to such herbicides is controlled by single genes which have been cloned and stably integrated into the genomes of crop plants which (transgenic plants) then show resistance to the herbicide. Thus, when the herbicide is applied in the farm, it kills only the weeds. The transgenic crop plants containing the herbicide resistance gene are not affected (Shah et al., 1986; De Block et al., 1987; Schell et al., 1989).

(h) Genetic engineering for insect resistance: Insect pests constitute a major hazard to crops. It has been found that the bacterium, Bacillus thuringiensis, produces a protein which, when ingested by certain insects (mainly in Lepidoptera and Diptera), generates an active, lethal toxin in their guts, and kills them in a short time. The toxin does not have any effect on human beings, other animals and beneficial insect groups such as bees. The Bt gene coding for the protein has bqen cloned and successfully integrated into the genome of several plant species (Fischhoff et. al., 1987; Vaeck et al. 1987; Schell et al., 1989). Such transgenic plants containing the Bt gene are pr tected from insect attacks and damage.

(i) Genetic engineering for virus tolerance: Viruses also contribute to heavy yield losses and damage to many crop plants. However, it has been found that plants infected by wild strains of viruses acquire resistance to subsequent infection by a more virulent strain. This phenomenon termed "cross-protection", has been demonstrated for a large number of viruses. It has also been shown that cross-protection is provided by the coat protein (CP) of the mild, inducing virus. These findings have led to the production of transgenic plants in which CP genes of certain viruses have been incorporated (Tumer et al, 1987 ; Nelson et al., 1988; Fauquet and Beachy, 1990; Beachy, 1991). Such transgenic plants show resistance to infection and damage by a number of viruses.

Another attractive objective or priority area in plant genetic engineering research is the possibility of inserting nitrogen fixing (Nif) genes from bacteria that grow naturally in some crops' roots into cereal crops. Such transgenic cereal crops would thus acquire the capacity to generate their own nitrogen fertilizer through atmospheric nitrogen fixation. This would facilitate rapid food production and minimize costly fertilizer imports. However, no positive results of success in this kind of research has been reported.

2. Microbial Biotechnology:

Microbial biotechnology is an area of much potential and interest to Africa in the application of biotechnology to agriculture and also to industrial development. The areas of interest are biofertilizers, industrial enzymes; single cell proteins, bio-insecticides, and biogas generation.

(a) Biofertilizers: Some soil micro-organisms have direct beneficial effect on the plant and thus can be classified as bio-fertilizers. Examples are nitrogen-fixing micro-organisms, mycorrhiza fungi, and plant growth promoting rhizobacteria. Use has been made of some micro-organisms that can fix atmospheric nitrogen to produce nitrogen-rich compounds which then become available to crops. Examples are blue-green algae (cyanobacteria), *Azotobacter*, *Klebsiella*, *Rhizobium*, and *Bradyrhizobium*, and *Actinomycetes*. While some of these are free-living, rhizobia infect roots of host plants where they form nitrogen-fixing nodules. Another example is the symbiotic association between *Anabaena azolla* and the water fern, *Azolla sp.* (see Johnston, 1989).

Effective biological nitrogen fixation (BNF) avoids the use of chemical nitrogen fertilizers which pollute the soil, and provides a cheaper and cleaner means of nitrogen fertilization to enhance the productivity of degraded African soils. Already, *Rhizobium* innoculant production is being commercialized in Africa (Ssali and Keya, 1985). Further research is required to fully commercialize the production and distribution of

Rhizobia innoculants, and the application of Azolla -Anabaena associations to enhance the fertility of African soils.

(b) Industrial enzymes: Many enzymes of importance to industrial processes are cheaply produced by employing micro-organisms. Notable examples are industrial carbohydrases such as α-amylase, β-amylase, pullulanase, amyloglucosidase, and enzymes of the cellulase complex. These enzymes find application in brewing industry as aids in saccharification (sugar formation from) of starches. This is an area of interest to many developing countries of Africa in search of local maltable grains for their breweries. Besides, microbial production of pectinases used in wine clarification as well as in jam and marmalade industries, is another example. Pectinases are also important for manufacturing detergents, in baking and in beer brewing. Enzymes of the cellulase complex such as endoglucanases, exoglucanases, and β-glucosidase, hold great promise as tools for the hydrolysis of cellulosic wastes into sugar syrup capable of serving as substrate in a variety of industrial fermentations. Potentially cheap sources of cellulose are available, as it is a major component of municipal wastes and of residues from paper industries. One formidable problem in the utilization of ligno-cellulosic waste products is how to achieve efficient hydrolysis of the recalcitrant cellulose component. The problem could however be surmounted by application of certain cellulase-complex enzymes from procaryotes and fungi.

(c) Single cell proteins: Single cell proteins (SCP) production refers to the conversion of a large variety of raw materials e.g. methanol, ethanol, sugars, petroleum hydrocarbons, industrial and agricultural wastes into microbial biomass which can be processed into protein-rich food and animal feed. In the African context, SCP can be an important supplement in local starchy foods which need protein enrichment for better nutrition e.g. "garri" and "ogi" in Nigeria. Cheap industrial and agricultural wastes are abundant for use in formulating the required feed stock. Examples are crude oil wastes, mollasses and waste products from sugar refineries. African local strains of yeasts such as Saccharomyces cerevisiae are available to act on the above substrates, while others like Endomycopsis and Candida utilis could be grown on starchy wastes (Obi, personal communication).

(d) Bio-insecticides: As stated earlier, Bacillus thuringiensis produces a protein which, when ingested by an insect, generates an active, potent and lethal toxin in its gut. This knowledge has been used in converting colonies of B. thuringiensis (serotype H14) and B. sphaericus (strain 1593) into powder form and the powder used as an insecticide. Such colonies could be produced using agricultural wastes as feed stocks. The powders have been successfully assessed in field trials for the control of mosquito larvae (vectors of malaria) in Nigeria (Obi and Obeta, personal communication). Further tests are continuing, to evaluate toxin production by other local species and strains of Bacillus. Applications of B. thuringiensis colony powder has now been extended to the control of the pesticide-resistant blackfly vectors of river blindness in West Africa (Bunders, 1990). More research along the lines given above are called for in order to scale-up the production of the bacteria, as well as lead to the discovery of other entomo-pathogens which could be used as bio-insecticides.

(e) Bioenergy (through biogas) production: Biogas production is based on the anaerobic conversion of hydrocarbons such as sugars, cellulose and organic matter into methane and carbon dioxide by mixed populations of thermophillic micro-organisms (Bunders, 1990). Biogas digesters supplied with manure or wastes from livestock, crop residues, etc., produce biogas which is used as an energy source for domestic purposes, and the remaining organic residues which are used as compost. Thus, in the promotion of the use of alternative sources of energy, to help in the conservation of dwindling supplies of petroleum, biogas generation holds great promise for rural areas of African countries. Numerous biogas generation plants are operational in China, India, and other Asian countries, using cow dung as substrate. Biogas use also relieves pressure on over-dependence on fuelwood, a major course of deforestation.

3. Animal Biotechnology:

Biotechnology could contribute to the improvement of livestock production in Africa in several ways. These include animal reproduction research with particular reference to cryo-preservation of sperm cells in semen from elite bulls at super-low temperatures (-196^{o}c) and subsequent use in artificial insemination. Also important are experiments on superovulation, in vitro ova culture and fertilization, culture of the embryos followed by transfer to "surrogate" mothers.

These techniques are useful in rapid improvement of economic traits of animals, including milk production, rate of meat-animal growth, preservation of genetic material (e.g. semen, ova, embryos) of economic importance long after they are made available for breeding, and years after the animals that first produced them are dead.

Also of importance is animal health where intensification of research is called for to promote production of vaccines against various animal diseases. In the long term, attention should be paid to new vaccines produced through recombinant DNA technology.

4. Aquatic Biotechnology:

The rivers, lakes and oceans are great reservoirs of food and of biological resources for mankind. They are expected, therefore, to form a major source of food for the future. However, the aquatic environments worldwide are prone to easy pollution, hence damaging the valuable water-based resources. There is, therefore, an urgent need for education and training in aquatic biotechnology, including aquaculture, water clean-up, and pollution control. This need is most urgent in Africa and other developing countries which together produce 45% of the world's 85 million tonne fish annually. In the short-term, improved management of fish farms, fingerling selection and production under modern methods, production of other aquatic food organisms such as prawns, crayfish, and oysters, should be encouraged.

Research and production of transgenic fish through rDNA methods qualifies as a long-term goal. India is using rDNA techniques to improve the productivity of the small-bodied tilapia fish. Their scientists are attempting to clone the bovine growth hormone gene, and micro-inject it into the fertilized tilapia egg to induce formation of larger fish.

HEALTH:

In the health sector, attention should be focussed on major health problems, especially those that can be solved through biotechnology R&D. Relevant areas include (1) Development of rapid diagnostic techniques, (2) Vaccine production, and (3) Development of therapeutic agents from local plant sources.

1. Development of rapid diagnostic techniques:

The following aspects are of importance: (a) Production of culture media, (b) Diagnostic agents, and (c) Monoclonal production.

(a) Production of culture media: Several possibilities exist for the production of culture media from local raw materials in African countries. These media can then be tested extensively for their efficiency of plating. They can be easily commercialized as there is a good market for them in developing countries.

(b) Diagnostic reagents: Production of reagents for diagnosis of viral, rickettsial and chlamydial infections of man and animals are of importance to developing countries. Such reagents as antigens, antisera and complements, can be prepared. However, such preparations require extensive tissue culture and biotransformation studies.

(c) Monoclonal antibody production: The basis for monoclonal antibody (MAb) technology is the fusion of an antibody-producing mammalian cell (e.g. spleen) with myeloma (cancer) cell to produce a hybridoma cell. When stimulated by an antigen such as a virus, the hybridoma will grow and produce a specific antibody, named monoclonal antibody, against the antigen (Bunders, 1990). The MAbs are then harvested from the liquid medium in which the hybridoma cells were cultured. The MAb technique may be used for diagnostic purposes to identify pathogenic organisms (e.g. viruses, bacteria, and parasites). One major advantage of MAb tests in diagnosis is their speed, accuracy and specificity. MAb can also be used in therapeutic treatment since it can serve to deliver cytotoxic drugs to tumour cells alone because of surface differences between normal and maligant (or tumour) cells.

2. Vaccine production:

In developing countries, including Africa, potent vaccines can be prepared using local strains of organisms. Producing a vaccine locally has many advantages. For example, it ensures availability at all times; it gives better protection since it would be from a local strain; and deterioration of imported vaccines due to improper storage (e.g. in the hot, humid, tropical environments) would be minimized.

3. Research on local therapeutic agents:

Many African countries lie along the tropical and subtropical latitudes. These regions house a vast flora of amazingly diverse plant families and species many of which are yet to be named, described and classified. Some of these plants are rich in useful primary and secondary chemical compounds including therapeutic agents. The flora of these regions needs to be extensively and exhaustively explored in order to discover those that contain substances of medicinal/therapeutic and industrial importance. Compounds that could be isolated and purified include anti-tumour drugs, sweetness, dyes, flavour,and aroma/fragrance compounds. Some of the plants containing these compounds (e.g. Thaumatoccus danielli producing the protein sweetness thaumatin, and Dioscoreophyllum cuminsii also producing the protein sweetner monellin have habitats in the tropical forests which are being decimated by human deforestation activities, accidental or deliberate fires, etc., thus threatening them with extinction. Such endangered species can be rescued by germplasm preservation techniques in tissue culture, and studies could lead to their cells being cultivated and the important compounds being produced by the cultured cells as has been achieved for shikonin, pyrethrin, etc. (Anon, 1984; Bunders 1990).

INDUSTRY:

Under the section on microbial biotechnology, attention was drawn to the role of microbes in facilitating various processes including biogas generation, production of bio-insecticides, and production of industrial enzymes. These could correctly be described as industrial biotechnology productions. However, the major application of biotechnology to industry is exemplified by fermentations, and these ought to be promoted in Africa. The most important industrial biotechnology in this regard is alcoholic fermentation. The importance of alcohol in industry and other sectors of the economy, including use as organic solvent, in beverages, energy source, and as automobile fuel, etc., is immense. Other microbial biotechnology processes involving fermentations that yield products of industrial importance include those for the production of amino acids, antibiotics, and other primary and secondary metabolites e.g. citric acid.

BIOTECHNOLOGY AND FOOD PROCESSING:

Although the food crisis in Africa is caused by declining food production, on the one hand, and by uncontrolled population growth in the region on the other; it is known that a considerable percentage of the food produced is lost due to post-harvest spoilage. If biotechnological methods can be deployed to prevent such losses, most of the food that is produced can be saved and made available to the people, thus reducing the food crisis. Several avenues are worthy of investigation, such as microbial fermentations of foods, detoxification, (Okafor, 1981; Okafor and Ejiofor, 1990) etc.

CONSTRAINTS IMPEDING AFRICAN BIOTECHNOLOGY:

Many problems and constraints impede biotechnology R&D in Africa. These include low funding, poor infrastructure such as lack of adequate laboratory space, equipment and their spare parts and maintenance, unvailability of reagents and other chemicals and supplies, unreliable water and electric power supplies. Manpower with the specialized skills for modern biotechnology R&D, especially for rDNA technology, is grossly inadequate. Another major drawback is the lack of relevant and current literature and data base on biotechnology.

In a recent survey, by questionnaire, of biotechnology scientists in sub-Sahara African countries, conducted by the author (Okonkwo, 1991), just over 100 responses were received from 19 countries. Of these, 90% were in plant biotechnology (employing cell and tissue culture procedures), 30% were in microbial biotechnology, 7% in animal biotechnology, and 2% in human health biotechnology. Less than 5% were engaged in recombinant DNA research. There were overlaps; for example, some scientists were engaged in both plant and microbial biotechnology. In view of the above, only mostly non-sophisticated biotechnologies are being and can be undertaken in Africa at the present time, with only minimal attention being given to genetic engineering.

SOLUTIONS TO THE CONSTRAINTS AND MODALITIES FOR ADVANCEMENT

1. Education and Training:

Most African countries do not yet have the critical mass of scientific manpower to undertake studies in modern biotechnology, which is a prerequisite for the latter's deployment to solve problems. Thus, it is necessary to first plan for biotechnology R&D by increasing the quantity and quality of scientific personnel in the fields of physiology, biochemistry genetics, microbiology and molecular biology. This will provide the pool of scientists that can embark on more specialized biotechnology research and training activities. In this regard, it is advisable for developing African countries to revise the curricula of their national colleges, polytechnics and universities so as to include courses in modern biotechnology.

Modes of training programmes to be planned for include postgraduate fellowships to support capable students in research leading to M.Sc. degree (2 years), and Ph.D degree (3 years), post-doctoral fellowships (1-2 years) for advanced training in biotechnology in outstanding international research laboratories in developed and developing countries. Besides, it is advisable to organize periodically, on regional or inter-regional basis, intensive training courses (1-2 weeks) on basic and advanced techniques used in biotechnology research, taught by experts in the fields. The courses should be mounted in laboratories that are well-equipped and staffed for the particular discipline taught, for example, the International Agricultural Research Centres (IARCS), Universities, and/or National Research Institutes, etc.

2. Information Acquisition and Exchange:

Scientists in Africa are isolated and frequently ignorant of the latest advances in most areas of science and technology (S&T). This is the result of unavailability of scientific information such as journal publications, books, symposia proceedings and monographs on topical subjects. Deliberate efforts should be made, as part of capacity building, to establish data bases in African countries, and, with assistance from relevant international organizations, gain access to international data banks. A system should also be established for them to acquire journals, books and other relevant up-to-date literature at reasonable cost. Assistance on the modalities can be obtained from agencies such as UNESCO, ICSU's CODATA, and the Third World Academy of Sciences (TWAS).

3. Networks, Linkages and Coordination:

National and regional efforts at capacity building in biotechnology must be supported by adequate networking, linkages and coordination. At the national level, wherever possible, it is desirable to establish a Centre for Genetic Resources, Genetic Engineering and Biotechnology which will serve as a focal point for organization and coordination of biotechnology R&D in the various institutions and private sector in the country. It will also serve as a vehicle for regional and international linkages for acquisition and exchange of information on biotechnology matters. This centre must, however, not operate in isolation, but should be integrated effectively with other national agricultural, industrial, health and S&T programmes for complementarity. Besides, those African countries with critical mass of scientists engaged in biotechnology R&D should each establish a national biotechnology society. Through scientific activities such as annual conferences, seminars and symposia, the society will be able to catalyse and build up research strengths, provide a forum for discussion of research projects, results achieved, and for assessment of possibilities for commercialization of products, and for consideration of future commitment of scientists to R&D, collaboration, in-depth studies and fast achievement of results, without duplication of efforts.

Networking has been widely accepted as a useful method for coordination of scientific activities and for exchange of information regionally, inter-regionally, and inter-nationally. Networks in biotechnology R&D are beginning to develop in

Africa. For instance, two such networks which have developed recently are worthy of note:

The African Plant Biotechnology Network (APBNet) was established in Nairobi, Kenya, in January 1989, with a coordinating office at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, and with sub-regional offices for West, Central, East, North and Southern Africa. The Coordinator based at IITA has been collecting and collating data (obtained through questionnaires) on manpower, which have been embodied in a directory of African Plant biotechnologists, first published in 1990 (Ng, 1990).

Similarly, ICSU-UNESCO's African Biosciences Network (ABN) has established a sub-network for biotechnology, following an international symposium on the food crisis in Africa, at Yamoussoukro, Cote d'Ivoire, in July 1989, and appointed a Coordinator (Okonkwo, 1989). Again, a survey (through questionnaires) was undertaken, to assess the stati of manpower, research interests, infrastructure positions and constraints in biotechnology in sub-Sahara African countries. The information has been supplemented through visits, by the Coordinator, of selected African countries. A first edition of the directory has recently been produced (Okonkwo, 1991), and periodic updating is planned.

Development of other networks has also been recorded, such as UNESCO-UNEP's Microbiological Resource Centres (MIRCEN) networks for Applied microbiology and Biotechnology, starting with activities in Nairobi, Kenya, and spreading to other parts of Africa; also reported is the francophone Animal Biotechnology network.

It is hoped that with the cooperation and collaboration among these networks, a comprehensive knowledge and documentation of the stati of biotechnology R&D in Africa will emerge. This will enhance effective planning, exchange of information, and collaboration in research and training activities.

4. Other International Support Activities:

A number of international organizations have been playing significant roles in promoting and supporting S&T capacities in developing countries. Most of them have strong biotechnology components in their programmes. Some of them are intergovernmental organizations (IGOs) and agencies while others are non-governmental organizations (NGOs). Notable organizations playing active roles in supporting biotechnology activities include the IGOs such as UNIDO, UNESCO, FAO; and NGOs like ICSU and the Consultative Group on International Agricultural Research (CGIAR). All these organizations, by communicating and interacting with developing countries, are helping them to define, assess, and fashion programmes in S&T in general and biotechnology in particular.

For example, UNIDO's International Centre for Genetic Engineering and Biotechnology (ICGEB) is already making significant impact in strengthening and supporting biotechnology activities in developing countries. By initiating and catalysing the establishment of affiliated centres at national, subregional and regional levels, ICGEB is bringing biotechnology research to the grass roots. It is hoped that many more affiliate centres will be formed in Africa in the near future. The main areas of emphasis of ICGEB include training and education (by sponsoring training courses and making research fellowship awards), supporting communication and information exchange through sponsoring of seminars, symposia, and conferences/workshops on biotechnology; and establishing computerized informatics in biotechnology. It also awards research grants to support worthy proposals on biotechnology problems, submitted by scientists through affiliated centres.

Among the NGOs, the CGIAR, a conglomerate of 16 IARCs sponsored by the FAO and the World Bank, carries out research through internationally-recruited scientists and technologists to improve agricultural productivity in developing countries. Most of them are located in developing countries worldwide and apply tissue culture procedures in their agricultural biotechnology research thrusts. Some of them are currently upgrading their facilities for full attention to most aspects of modern biotechnology. They also organize various workshops, training courses and symposia in plant biotechnology for the benefit of scientists in developing countries.

The International Council of Scientific Unions (ICSU), an umbrella NGO of some 20 scientific unions, 75 national academies of science and research councils, and 26 associate scientific organizations, has its goal as fostering and encouraging cooperation in international scientific activity for the benefit of mankind, with special concern for the world's less developed countries. ICSU created the International Scientific Committee on Biotechnology (COBIOTECH) in 1986 with the objectives of stimulating activity and cooperation with appropriate organizations including the industrial community as regards advancement of research and education and transfer of information and resources in biotechnology (Gerhardt, 1990). COBIOTECH covers the entire breadth of biotechnology, and its activities are in three dimensions of research, education and information transfer. It has made a major input in its informational activities by publishing in 1991 a resource book titled "Biotechnology worldwide" edited by Coombs and Campbell (1991). The book contains reports on the state of biotechnology in 50 countries worldwide. COBIOTECH interacts and collaborates with other regional and international organizations such as the Federation of European Biotechnological Societies (FEBS), UNESCO, UNIDO/ICGEB(to which it is now an affiliate member), and UNDP.

5. Funding (National Governments & International Agencies):

A major impediment to development in most African countries is the paltry funding provided by governments for R&D (still at 0.2-0.3% of GNP). Developed countries commit 2-2.5% of their GNPs. However, recent advancements in S&T in a number of developing countries correlate with their increased funding of S&T (see Table 1).

Table 1: Expenditure of funds on R&D by some developing countries (After Hassan, 1990

Country	GNP	
	Previous	Now
Bangladesh	0.2	1.1
Brazil	0.6	2.1
Iran	0.5	2.0
Pakistan	0.17	1.0
Philipines	0.2	1.5
South Korea	0.6	2.0
Venezuela	0.4	2.0

interestingly, no African country qualifies for inclusion in that group. Unless African governments deliberately upgrade their budget allocations to S&T to at least 1% of their GNPs by the end of this century, progress in agricultural research, including biotechnology, and S&T in general, is bound to be stultified.

Additional support should be sought from the well-known UN organizations which have been giving grants to developing countries, such as UNIDO, UNDP, UNEP, UNESCO, FAO, and WHO; as well as others like the World Bank, ADB, GTZ, IDRC, and TWAS, etc.

6. <u>Policy issues</u>:

Many governments in African countries are either unaware of or insensitive to the contributions being made by their indigenous scientists in science and technology, not to talk of worldwide activities in the biotechnology field. They also seem not to appreciate the infrastructural constraints under which their scientists work. It is therefore essential to educate policy makers as well as the public in Africa on the potential benefits of biotechnology and the need for government and policy makers to support S&T efforts in Africa and to adequately fund biotechnology programmes. Attention has been drawn elsewhere to this need (Hassan, 1989; Okonkwo, 1990). Bodies such as the Organization of African Unity (OAU), the Economic Commission for Africa (ECA), and the African Development Bank (ADB) should join in the campaign to get African leaders to emulate other developing countries such as Iran, South Korea, Brazil, Venezuela, etc. that have upgraded their allocation of funds to S&T to at least 2% of their GNPs. The ADB should emulate the World Bank which now has its own biotechnology R&D programme.

In the specific area of biotechnology, in view of its immense potential for contributing to rapid development in Africa, a deliberate effort should be mounted to achieve rapid results. For example, there is need to popularize the role of biotechnology in solving socio-economic problems in Africa. Electronic and print media should be used to emphasize the benefits of biotechnology R&D. The production of new vaccines, new high-yielding, disease-resistant crop varieties, and biofertilizer development, for example, should be highlighted.

7. Risk Assessment and Biosafety Regulations:

It is essential that the public and policy makers in African countries should be aware of, not only the benefits of biotechnology but also the risks, especially with respect to genetic engineering research. It is possible for genes to "escape" from genetically engineered varieties, if care is not taken, and enter wild plants, e.g. in herbicide resistance. Therefore, all experiments involving recombinant DNA technology must have proper containment or quarantine conditions for the research and trials preceding the release of genetically modified organisms (GMOs). To this extent, individual African countries should establish functional and well-informed national review bodies and institutional bio-safety committees to assist government in formulating regulations to aid monitoring and regulating the release of GMOs into the environment. Other important regulatory matters which the countries should attend to are: the establishment and observation of a code of conduct; guidelines governing intellectual property rights and patents; including limits to patentable materials; and ethical issues, in biotechnology R&D.

The IARCSs, where they exist, also need to establish international biosafety committees and ensure that they function in accordance with the host country's regulations.

Finally, international development agencies need to ensure that bicsafety reviews are conducted prior to the release of GMOs in any projects they sponsor.

All the above regulations will ensure the conduct of biotechnology experiments and safe application of results without risk to environment. Besides, advice on rick assessment and on formulating the regulations and guidelines should be sought from international agencies and from developed countries with experience in such matters.

CONCLUSIONS:

From the above presentation, it seems clear that each country in Africa stands to benefit from biotechnology R&D by training her manpower for effective application of the "new" technology to agriculture, health care delivery, industrial production, and the envircnment. In doing these she must consider the benefits and risks, order her priorities, start with simpler biotechologies that address the most pressing problems, for short-term benefits, and embark on the more sophisticated ones later when their infrastructure improves, for long-term goals.

In agriculture, biotechonology will assist in improved control of pests and diseases, and thus better food security. For short-term benefits, improved plant propagation and fast breeding for many useful traits, through plant cell and tissue culture, improved soil fertility through biofertilizers from BNF, improved animal health and husbandry, and increase in food supply through appropriate food processing, seem most attractive.

In the human sector, biotechonology will bring about a healthier population through the introduction and use of a new generation of biotechnolcgy-produced vaccines and drugs against most tropical, endemic diseases of Africa.

Besides, mid- and long-term benefits of biotechnology will accrue from genetic engineering of plants and animals for improved resistance to diseases and pests. Deliberate efforts should be mounted to embark on these more sophisticated biotechnology R&D by planning for and deploying the conditions that will make them flourish.

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