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AGRICULTURAL BIOTECHNOLOGY AND BIO-SAFETY: TOOLS FOR ATTAINING FOOD SECURITY AND SUSTAINABLE INDUSTRIAL GROWTH IN NIGERIA.

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ABSTRACT

The current world population is about 6 million and it is excepted to increase to more than 8 million by the 2025 at an alarming rate of 80 million/year (95% of which will occur in the developing world). On average about 0.8 billion of the global population are food insecure, and about 400,000 die from hunger-related causes everyday. The situation is grim in Africa. With the highest growth of 3.1%, Africa's population is over 550 million today and is projected to increase to1.3 billion in the next 25 years. Nigeria is not left out in this, with a population of over/150 million major of its population, about 75% live in rural areas fighting food insecurity, poverty and deprivations. The challenges today are how to prepare for the unprecedented levels of global population and ensure that our teeming population has access to food at all times and to produce food in a sustainable way. To meet this projected populations need for food, crop food production must be doubled, from 2-4 billion metric tons/year. This increase in production will primarily come from increasing biological yield and not only area expansion and irrigation because land and water are becoming scare due to population increase. The response to this is to harness all instruments of sustainable agricultural growth and agricultural biotechnology is one such instrument. Biotechnology has the potential to provide new opportunities for achieving enhanced crop and livestock productivity, and improve food security and nutrition. It provides tools for adapting and modifying the biological organisms, products processes and systems found in nature. It provides a wide range of tools for industry to improve cost and environmental performance. This paper thus reviewed areas biotechnology could support for industrial growth and ends with strategies for effective use of biotechnology in Nigeria.

KEYWORDS: Agriculture, biotechnology, bio-safety, transgenic crops disease resistant, Nigeria.

INTRODUCTION

Poverty eradication and food security have moved to the centre stage of the global development agenda. These are the greatest global challenges and their redress is an indispensable requirement for sustainable development in developing countries, particularly in Africa (Boon and Ahenkan, 2002; WSSD, 2002). The world's leaders pledged their commitment to eliminate hunger, malnutrition and to halt global poverty by 2015 at the World Food Summit (WFS, 1996) and the Millennium Summit in 2006. At the World Summit on Sustainable Development (WSSD) held in Johannesburg in 2002, the international community reaffirmed its commitment to develop national and local programmes for sustainable development, poverty eradication and food security. The AU/NEPAD strategy for 2010-2015 also emphasizes poverty alleviation and putting African countries on the path to socioeconomic development. Despite these commitments, the last decade has witnessed an increased poverty level, especially in most African countries.

Worldwide, 854 million people still remain hungry and undernourished, of whom 820 million live in the developing countries (FAO, 2006). In one-third of African countries, the mean daily calorie availability per capita is below the intake level of 2350 calories recommended by FAO (2000). In addition, almost two billion people in the developing world suffer from iron deficiency, 140 million people experience iodine deficiency, and 140 million children experience vitamin A deficiency. As a result of low food availability and profound poverty, about 200 million people in Africa are undernourished or unable to meet their daily dietary energy requirements including 31 million children under five years of age, one in three of whom suffers from mental retardation, blindness, and other illnesses brought on by malnutrition (Mallaby, 2002). Although some data indicate that the global prevalence of child malnutrition has declined significantly in the last 25 years, in Africa the reduction of malnutrition is much lower compared to other continents (De Onis *et al.*, 2004), Today, extreme poverty ravages the lives of one in every four in the developing world (OECD, 2001). It is estimated that over 180 million people living in extreme poverty are found in the rural areas of Africa (World Bank 1996). This number is expected to exceed 300 million by 2020 (Amoako, 1999). About 80 % of all Africans live on a daily income of less than US$ 2 and nearly half struggle to survive on US$ 1 a day or less. Rural people strive to feed themselves, while the urban population spend more than 70% of its earnings on food, leaving only 30% for other minimum basic needs such as housing, education, health care, water and livelihood (Roy-Macauley, 2002).. Hunger, poverty and malnutrition are the main factors interacting to create an enormous set back to socio-economic development, especially in the rural areas of Africa.

The agricultural sector is the largest contributor to the economies and livelihoods of many African countries. It accounts for 35% of the continent's gross domestic product (GDP), 40% of export earnings and 70% of employment and it is expected that reliance on natural resources will remain high at least for the next generation (Dione, 2002). Over the last two decades Africa has witnessed a considerable decline in agricultural productivity, with the annual agricultural growth rate falling from 2.3 % in the 70s to 2.0 % between 1980 and 1992 (Roy-Macauley, 2002). The average yield for major food crops such as maize, rice and sorghum, stands at 1.5 tons/ha, compared to 4.9 tons/ha for China and 6.6 tons/ha for the USA (Roy-Macauley 2002). Some of the most important factors limiting agricultural productivity in Africa include small size of farms, inadequate water resources, poor crop varieties and livestock breeds, biotic and abiotic stresses, poor livestock forage, inadequate use of agro-inputs, poor rural infrastructure, inadequate technological base, poor marketing systems, inadequate financial resources and weak enabling policy environment.

With an increasing population and poor performing agriculture aggravated by invasive pests, weeds, land degradation, erosion, droughts and the effects of climate change, Africa faces one of the biggest challenges of its time - assuring its increasing population of a sustainable food supply (Mataruka, 2009). African population growth rates remain among the highest in the world, despite the projected increases in mortality resulting from infectious diseases, Africa's population is presently estimated at 840 million and is projected to increase to 1.75 billion by 2050 (FAO, 2006). While population grows at a rate of 3.5 % per annum, food production increase is 2.5 % or less depending on the country. As a result the per capita food production in Africa has been declining while the rest of the world has experienced an increase (FAO, 2002).

The most important global challenges today are:

a) To comprehend and prepare for the unprecedented levels of global population,
b) To ensure that this population has access to food in adequate quantities at adequate prices, everywhere at all times and,
c) To produce this food in a way that does not destroy the natural resources on which we all depend. The last two components combined form the challenge of sustainable food security.

The challenges we are facing today are both technological (requiring the development of new, high productivity, environmentally sustainable, production systems) and political (requiring policies that do not discriminate against rural areas). An essential aspect of the response to these challenges is to harness all instruments of sustainable agricultural growth; and agricultural biotechnology is one such instrument (Serageldin, 1999).

Biotechnology is the use of living organisms or parts thereof, to provide useful products for the benefit of humans. In other words, it is the use of biological processes to achieve specific purposes. Biotechnology is not a new science; it is as old as humans. The processes of fermentation, brewing, food processing (bread and cheese making) and traditional vaccines were being practiced since the existence of humans. These are collectively classified as traditional biotechnology.

Modern or advanced biotechnology constitutes:

a) Conventional biotechnology - which does not involve transformation of organisms or genetic manipulations. This includes tissue culture and micro-propagation, plant disease diagnostics, molecular breeding and marker assisted selection, animal production technologies, vaccine production, use of biopesticides, biofertilizers, bioherbicides, etc.
b) Gene manipulation - modern biotechnology that involves transformation of plants, animals and microorganisms to produce improved crops and farm animals through genetic engineering. These transgenic varieties are known as Living Modified Organisms (LMOs), Genetically Modified Organisms (GMOs) or Genetically Improved Organisms (GIOs).

Safe and proper use of biotechnology can play an important role in:

a) Improving food production and hence attaining food security.
b) Improving economic growth and alleviating poverty.
c) Providing food with improved nutritional value (Improve human health)
d) Providing environmentally safe and sustainable agriculture.
e) Cleaning and safeguarding the environment (Bioremediation).

Biotechnology has been found to provide new opportunities for achieving productivity gains in agriculture. Many scientific studies have concluded that the promise of biotechnology as an instrument of development lies in its capacity to improve the quality and quantity of crops and livestock, swiftly and effectively. Report prepared by Kendall *et al.,* (1997) stressed that the time required to identify and eliminate unfavourable traits through traditional crop breeding is greatly reduced by the use of genetic engineering techniques.

The application of biotechnology can create plants that are more resistant to drought and soil acidity and Stalinization. These attributes are critical to the development of agriculture in the poorest areas where soils are poorly endowed, Additionally plant characteristics can be genetically altered for earlier maturity, increased transportability, reduced post harvest losses, and improved nutritional quality. Vaccines against diseases afflicting livestock are already important products of biotechnological research (Morrison, 1999).

THE ROLE OF BIOTECHNOLOGY IN ATTAINING FOOD SECURITY

Biotechnology can make a major contribution to food and feed security and to the alleviation of hunger and malnutrition, which claims tens of thousands of lives everyday in the developing countries of Asia, Africa and Latin America. Since the last few decades, Biotechnology tools are increasingly being applied to crops and livestock-related needs of importance to developing countries. They often provide the only or best 'tool of choice' for improving the genetic component of agricultural productivity.

GM crop commercialization started in 1 996 and in 10 years time (1996 to 2005), a total of about 475 million hectares of GM crops were planted globally which met the expectations of millions of small and large farmers in both industrial and developing countries (Table 1). GM crops delivered significant agronomic, environmental health and social benefits to farmers and to global society and contributed to a more sustainable agriculture. Most of the early products of agricultural biotechnology focus on crop protection. In 1998, transgenic crops that are herbicide tolerant covered about 19.8 million hectares. Use of herbicide tolerant varieties greatly facilitates weed control using certain types of herbicide and greatly reduces the amount of herbicide applied to the crop for effective weed control. This also enables farmers to employ soil conservation practices such as minimum tillage, which reduces soil erosion (Serageldin, 1999).

Table I Global area of biotech crops 'Modified after: James, 2005)

Year	Hectares (Million)
1996	1.7
1997	11.0
1998	27.8
1999	39.9
2000	44.2
2001	52.6
2002	58.7
2003	67.7
2004	81.0
2005	90.0
Total	474.6

Another focus of agricultural biotechnology research was on increased plant resistance to pests. According to Serageldin (1999), an estimated 7.7 million hectares were planted in 1 998 to transgenic crops with introduced genes that produce substances toxic to target insect pests. The use of pesticides has dropped in areas using these crops, a positive impact not only on farm income but also on the environment. Since 1996, pesticide applications have been reduced by 1 72, 000 metric tons as a direct result of the use of biotech crops. The use of

GM soybeans has been one of the largest contributors to reduce pesticide applications, accounting for cumulative reductions of 41,000 metric tons (Monsanto, 2005). Australian farmers used 50% fewer pesticide applications on 8t cotton (Fitt, 2003).

Table 2: Global status of biotech crops in 2005

Country	Area (million ha)	%
USA	49.8	55.3
Argentina	17.1	19.0
Brazil	9.4	10.4
Canada	5.8	6.4
China	3.3	3.7
Paraguay	1.8	2.0
India	1.3	1.5
Others	1.5	1.7
Total	90.0	100%

In 2005, global area of biotech crops reached 90 million hectares, representing an increase of 11% from 2004 equivalent to 9 million hectares (Table 1). Remarkably, the global biotech crop area increased more than 50-fold in the first decade of commercialization. It is noteworthy that the top 5 countries include two industrial countries, USA and Canada and three developing countries, Argentina, Brazil, and China (Table 2). The global area of biotech crops grown by developing countries has increased every year from 14% in 1997 to 38% in 2005 (171% increase) (James, 2005). The main traits and attributes of commercial GM crops include herbicide tolerance (77%), insect resistance (1 5%) and herbicide tolerance and insect resistance, combined (8%) (James, 2005). The commodities that dominate the global biotech market are given in Table 3.

Table 3 Commodities that dominate global biotech markets

Commodity	Area (million ha)	%
Soyabeans	54.4	60
Corn	21.2	24
Cotton	9.8	11
Canola	4.6	5

The majority of agricultural scientists anticipate great benefits from biotechnology in the coming decades to help meet our future needs for food and fibre. The commercial adoption by farmers of transgenic crops has been one of the most rapid cases of technology diffusion in the history of agriculture. Between 1996 and 1999, the area planted commercially with transgenic crops has increased from 1.7 to 39.9 million ha. (James 1999). In the last 20years, biotechnology has developed valuable new scientific methodologies and products, which need active financial and organizational support to bring them to fruition. So far, biotechnology has the greatest impact in medicine and public health. However, there are a number of fascinating developments that are approaching commercial applications in agriculture.

Transgenic varieties and hybrids of cotton, maize and potatoes, containing genes from *Bacillus thuringiensis* that effectively control a number of serious insect pests, are now being successfully introduced commercially in many parts of the world. The use of such varieties will greatly reduce the need for insecticides, Transgenic wheat with high gludehydrogenase, for example, yielded up to 29% more crop with the same amount of fertilizer than did the normal crop. Transgenic plants that can control viral and fungal diseases are not nearly as developed. Nevertheless, there are some promising examples of specific virus coat genes in transgenic varieties of potatoes and rice that confer considerable protection. Other promising genes for disease resistance are being incorporated into other crop species through transgenic manipulations. Rice is the only cereal that has immunity to the Puccinia specie of rice. Imagine the benefits if the genes for rust immunity in rice could be transferred into wheat, barley, oats, maize, millet and sorghum. The world could finally be free of the scourge of rusts, which have led to so many famines over human history. Considerable progress also has been made in the development of transgenic plants of cotton, maize, oilseed rape, soybean, sugar beet, and wheat, with tolerance to a number of herbicides. The development of these plants could lead to a reduction in overall herbicide use through more specific interventions and dosages. Not only will this development lower production costs; it also has important environmental advantages.

Good progress has been made in developing cereal varieties with greater tolerance for soil alkalinity, free aluminum, and iron toxicities. These varieties will help to ameliorate the soil degradation problems that have developed in many existing irrigation systems. These varieties will also allow agriculture to succeed in acidic soil areas, thus adding more arable land to the global production base. Greater tolerance of abiotic extreme, such as drought, heat, and cold, will benefit irrigated areas in several ways. We will be able to achieve more crops per drop by designing plants with reduced water requirements and adopting between crop/water management systems. Recombinant DNA technique can speed up the development process.

There are also hopeful signs that we will be able to improve fertilizer-use efficiency by genetically engineered wheat and other crops to have high levels of glucose. The power of genetic engineering to improve the nutritional quality of our food crop species is also immense. Scientists have long had an interest in improving maize protein quality. More than 70 years ago, researchers determined the importance of certain amino acids for nutrition. More than 50 years ago, scientists began a search for a maize kernel that had higher levels of Lysine and Tryptosine, two essential amino acids that are normally deficient in maize. Thirty six years ago, scientists at Purdue University (West Lafayette, IN) discovered a floury maize grain from the South American Andean highlands carrying the opaqite-2 gene that had much higher levels of Lys and Trp. But as is often the case in plant breeding, the highly desirable trait turned out to be closely associated with several undesirable ones. The dull, chalky, soft opaque-2 maize kernels yielded 15% to 20% less grain weight than normal maize grain. However, scientists from the international maize and wheat improvement center (Mexico city) who were working with Opaque-2 maize observed little islands of translucent starch in some opaque-2 endosperms. Using conventional breeding methodologies supported by rapid chemical analysis of large numbers of samples, the scientists were able to slowly accumulate modifier genes to convert the original soft opaque-2 endosperm into vitreous, hard endosperm types. This conversion took nearly 20 years. Had genetic engineering techniques been available then, the genes that controlled high Lys and Trp could have been inserted into high-yielding hard-endosperm phenotypes. Thus through the use of genetic engineering tools, instead of a 35-year gestation period, quality protein maize could have been available to improve human and animal nutrition 20 years earlier.

Recently, scientists from the Swiss Federal Institute of Technology (Zurich) and the International Rice Research Institute (Los Banos, the Philippines) have succeeded in transferring genes into rice to increase the qualities of vitamin A, Iron, and other micronutrients. This work could eventually have profound impact for millions of people with deficiencies of vitamin A and Iron, causes of blindness and anemia respectively.

Because most of the genetic engineering research is being done by the private sector, which patents its inventions, agricultural policy makers must face a potentially serious problem. How will these resources-poor farmers of the world be able to gain access to the products of biotechnology research? How long and under what terms, should patents be granted for bioengineered products? Furthermore, the high cost of biotechnology research is leading to a rapid consolidation in the ownership of agricultural life science companies. Is this consolidation desirable? These issues are matters for serious consideration by national, regional and global governmental organizations

National governments need to be prepared to work with and benefit from the new breakthroughs in biotechnology. First and foremost, governments must establish regulatory frameworks to guide the testing and use of genetically modified crops. These rules and regulations should be reasonable in terms of risk aversion and implementation costs. Science must not be hobbled by excessively restrictive regulations. Since much of the biotechnology research is under way in the private sector, the issue of intellectual property rights must be addressed and accorded adequate safeguards by national governments.In addition to advanced biotechnology techniques, the contributions of Tissue Culture Technique to agriculture, especially in mass multiplication of improved crop varieties for rapid dissemination to farmers, cannot be overemphasized.

Biotechnology, Food Security and Nigeria Vision 2020

Food security refers to the availability of food and one's access to it. A household is considered food secure when its occupants do not live in hunger or fear of starvation. World-wide around 852 million men, women and children are chronically hungry due to extreme poverty, while up to 2 billion people lack food security intermittently due to varying degrees of poverty (FAO, 2003). As of late 2007, increased farming for use in biofuels, world oil prices at more than $100 a barrel, global population growth, climate change loss of agricultural land to residential and industrial development and growing consumer demand in China and India have pushed up the price of grain. Food riots have recently taken place in many countries across the world.

It is becoming increasingly difficult to maintain food security in a world beset by a confluence of "peak" phenomena, namely peak oil, peak water, "peak grain" and "peak fish." More than half of the planet's population, numbering approximately 3.3 billion people, lives in urban areas as of November 2007. Any disruption to farm supplies may precipitate a uniquely urban food crisis in a relatively short time. The ongoing global financial meltdown has affected farm credits, despite a boom in commodity prices.

A direct relationship exists between food consumption levels and poverty. Families with the financial resources to escape extreme poverty rarely suffer from chronic hunger; while poor families not only suffer the most from chronic hunger, but are also the segment of the population most at risk during food shortages and famines.

Nigeria is yet to achieve food self sufficiency and food security, spending about $3 billion on food import annually. Our agriculture is still at subsistence level, with low productivity and poor return on investment. To complement our food supply, the country is still largely dependent on imports of wheat, rice, sugar, milk and many other food items. However, it is aimed that in the medium term substantial import substitution should be achieved for rice, sugar and wheat. To achieve self sufficiency, specific targets have been estimated for achievement in the intervention period (2008 - 2011). A deliberate programme to develop/acquire and disseminate improved technologies, including biotechnology to our farmers is certainly one of the strategies for achieving the set targets.

The attainment of food security is sine quo none and one of the basic objectives for any nation. In the hierarchy of needs, food is crucial as it ensures one of the first order conditions, namely, survival. Agriculture is the primary means by which man has satisfied the requirement for food and nutrition. With increasing population growth, the trend has been to bring more land under cultivation and this requires the cutting down of both forest and grass lands for agricultural production. Agricultural biotechnology therefore holds great potentials in addressing the issue of food security in the face of population growth, among other things. Other issues which agricultural biotechnology has the capacity to address include land use, deforestation, environmental degradation, erosion, flooding, etc.

The benefits of agricultural biotechnology are quite wide and varied. For instance, the need to cut and burn large swaths of grassland may be reduced or even eliminated through crop varieties that have been genetically modified to be herbicide-resistant. Similarly, the pressure to open tip more lands for cultivation is greatly reduced and sometimes eliminated through application of biotechnology. Agricultural biotechnology, as stated earlier, results in quantum increases in crop yields and livestock production. As a result, agricultural activities impact less oh the environment through the application of biotechnology, while increasing yields at the same time. This serves to preserve the environment, forests and grasslands, biodiversity, the ecology and mitigate climate change and ensure sustainable development. It is therefore, in recognition of the potential contributions of biotechnology to the country's developmental aspirations that government had made it an integral part of its overall science and technology policy. To address the issue of food security for a teeming population of 140 million certainly requires the application of biotechnology in meeting this need. Highly populated countries such as Mexico, Pakistan, India and China have utilized agricultural biotechnology to feed their populations and so much succeeded that a country like China with a population of over 1.3 billion has now emerged as the largest food producer.

Consequently, there is a national policy on biotechnology which has been designed to drive Vision 2020 in the short and medium terms. Among other objectives of the policy is; the development of suitable mechanisms and activities to support the emergence of biotechnology enterprises for the commercialization of biotechnology products; so as to ensure a sustainable food security, job and wealth creation, efficient and cheap healthcare delivery as well as a safe environment.

Requirements for effective use of Biotechnology:

For effective utilization of biotechnology and its products, Nigeria would require immediate attention in the following areas:

1. Provision of Containment/confinement Facilities

The need for containment/confinement facilities for responsible development and use of GM Crops is inevitable. Containment facilities for handling products of trials in transgenics and for their safe disposal are necessary. There is need to establish confined field trials in various agro-ecological zones of the country for effective evaluation of GM-Crops. The Zonal Coordinating NARIs would be of great advantage here. The ARCN recognizes the importance of containment facilities and is making plans to provide same in our NARIs.

2. Manpower Development (human capacity building)

The development of a strong capability in the plant sciences is an absolute priority for all national research programs. This is necessary because only local plant breeding can address local agricultural environments, and only local initiatives can appreciate cultural and local environmental preferences.

The international research centers (those under CGIAR) and our national research programs must collaborate with advance research institutions to increase their efforts to extend the Biotechnology techniques to all crops of national interest including horticultural crops like fruits and vegetables which are important to developing countries.

If Nigeria will benefit from the potential advantages of biotechnology, especially the GM technologies, it will be important to promote capacity building in risk management. It is therefore important to:

1) Build sufficient scientific and technical human resources to enable it to assess the relative benefits and the risks of GM technology.
2) Develop simple techniques to readily and reliably distinguish non-transgenic and transgenic plants where necessary.
3) Monitor and evaluate the short, mid and long term effects of transgenic plants and share data between all relevant stakeholders.
4) Research institutions should be equipped with molecular geneticists, plant breeders, laboratory safety analysts and other personnel needed.

3. Strong Biosafety Regulatory System

Nigeria needs to put in place and strengthen a competent regulatory system in the event that we decide on the development and use of transgenic crops in the country. In view of the fast way improved technology are disseminated worldwide, Nigeria better prepare for the GM Crops, as the tendency is that if we close our doors to GM crops, we may eventually find them trooping in through the back door illegally.

Scientific human capacity to adequately handle research and development of GM crops are available at our National Agricultural Research Institutes, although these would no doubt require strengthening through training and retraining, establishment of containment facilities and provision and equipment of high-tech laboratories. The Agricultural Research Council of Nigeria(ARCN) recognizes the importance of these needs and is committed to ensuring that they are provided.

The ARCN, in order to resolve some of the issues raised above, is putting in place some strategies for effective development and use of biotechnology as follows

i) The ARCN recognizes the importance of biotechnology and genetic resources and has accordingly put in place a Plant Genetic Resources Division to adequately coordinate developments in this area within the Nigerian NARIs.
ii) The ARCN is assessing the state of biotechnology research in the NARIs
iii) Recognizing the importance of IPR to the sustainable development of biotechnology research, the ARCN plans to develop IPR policy and management guidelines for agricultural, research in the country soonest.
iv) The ARCN is. also taking steps to establish gene banks in our Zonal Coordinating Research Institutes in each agro-ecological zone of the country. This is with a view to conserve the genetic diversity in the zones.
v) ARCN is also working towards establishment/upgrading of biotechnology laboratories and the provision of confinement facilities in all the NARIs for effective biotechnology research and development.
vi) The ARCN is committed to the strengthening of the Institutional Biosafety Committees of the NARIs.

4. Setting priorities and research agenda for biotechnology R&D

African development problems are numerous and multidisciplinary in their nature and biotechnology in isolation is unlikely to solve them (lzquierdo, 2000). African countries need to identify specific biotechnology priority areas that offer high potential for contributing to the economy and people's livelihood Food security. Nutrition, healthcare and environmental sustainability are among Africa's biggest challenges. Biotechnology should not be seen as a technology for a 'quick fix' for Africa's problems. Rather it should be viewed as one part of a comprehensive, sustainable poverty-reduction strategy African countries must exploit a range of options to ensure that future biotechnology initiatives reach their full potential for alleviating poverty, securing food security and reducing impact of biotic and abiotic stresses.

African countries need to develop knowledge appropriate to their own situations and choose the most appropriate biotechnology tools. Biotechnology expertise should complement existing technologies and he demand- and product-driven. Biotechnology is expensive and requires more skills than conventional technology. So it should be used only to solve specific problems where it has comparative advantage.

Biotechnology investment strategies should also address the needs of the poor, who depend on agriculture for their livelihoods, particularly in marginal areas where productivity increases will be difficult to achieve. In addition to technical considerations, priority setting should take into account national development policies, private sector interests and market opportunities. Since African countries lack adequate resources, infrastructure and the business environment to attract new technologies and related investments, biotechnology development agendas need to he developed taking into consideration Africa's opportunities and constraints. The strategy should include lessons learned, best-practice examples, strategic partnerships that are successful, products and processes proven to work and ways to encourage new innovative ideas and initiatives.

Nigeria and Biotechnology:

The Nigerian Government believes in the opportunities offered by biotechnology to empower our farmers through increased productivity, thereby alleviating poverty and creating wealth ultimately economically empowering them. This has led to the creation of a National Biotechnology Development Agency (NABDA). The Ministry of Agriculture through the Agricultural Research Council of Nigeria (ARCN) has kept a very close relationship and partnership with both international organizations such as the International Agricultural Research Centres of the Consultative Group on International Agricultural Research (CIGIAR: ICRISAT, IITA, CIAT, WARDA, Biodiversity International (IPGRI), IFPRI, etc); the Food and Agriculture Organization (FAO) of the United Nations (UN); the Forum for Agricultural Research in Africa (FARA), CORAF/WECARD; and the African Agricultural Technology foundation (AATF). We will also continue to maintain close collaboration with other Nigerian Governmental Agencies such as the National Biotechnology Development Agency, the National Centre for Genetic Resources and Biotechnology (NACGRAB), the Biosafety Desk-Office of the Federal Ministry of Environment, Biotechnology Centres in the Federal Universities, and NGOs working on Biotechnology and Biosafety related issues. We are presently in partnership with AATF based in Kenya, and through the ARCN about signing a Memorandum of Understanding (MoU) with them to work together in bringing improved technologies, including biotechnology products, to our farmers.

We are also aware that marker-assisted selection and DNA fingerprinting allow a faster and much more targeted development of improved genotypes for all living species. They also provide new research methods which can assist in the conservation and characterization of biodiversity. The new techniques will enable scientists to recognize and target quantitative trait loci and thus increase the efficiency of breeding for some traditionally intractable agronomic problems such as drought resistance and improved root systems. Realizing all these potentials of Biotechnology, the ARCN is repositioning all our Agricultural Research Institutes to be fully ready for the challenges of biotechnology research and biotechnology products. The Institute for Agricultural Research, Samaru-Zaria in partnership with AATF; and the National Root Crops Research Institute, Umudike through the Bio Cassava Plus project of the Global Consortium on Cassava, are about commencing transgenic cowpea and transgenic cassava research respectively.

Biosafety mechanisms

Developing countries that are pursuing the safe and effective use of modern biotechnology recognize the need to have in place effective regulatory systems at national and institutional levels, compatible with international best practice. Biosafety refers to "mechanisms aimed at ensuring careful design, transfer, handling and use of biotechnology and its products. It is a principle that tempers the adoption of a new technology with careful consideration of its potential effects on human health and the environment. "National Biosafety systems serve as mechanisms for ensuring the safe use of biotechnology and its products without imposing unacceptable risk to human health or the environment, or unintended constraints to technology transfer. International dialogue regarding concerns for the regulation and review of new agricultural products gave rise to the Cartagena Protocol on Biosafety (CPB) on 29 January 2000. The objective of the protocol is; "to contribute to ensuring an adequate level of protection in the field of the safe transfer, handling and use of LMOs resulting from modern Biotechnology that may have adverse effects on the conservation and sustainable use of biological diversity, taking into account risks to human health, and specifically focusing on trans-boundary movements.

For developing countries, functional biosafety systems are key to maximizing the benefits from biotechnology because they demonstrate to stakeholders and the public that attendant environmental and health issues are addressed by scientific risk assessments.

WHAT ARE THE IMPLICATION OF BIOTECHNOLOGY TO NIGERIA

Agricultural growth in Nigeria is severely constrained by rainfall shortages especially in the North compounded by soil degradation, overgrazing and deforestation. We therefore need to develop crops and livestock breeds that are early maturing and adaptable to the harsh climatic conditions of the country. Moreover, as arable land becomes scarce with increasing population, harnessing all instruments of sustainable agricultural growth through the application of agricultural biotechnology is the best alternative to increase productivity and hence attain food and feed security in the country.

The tangible benefits of biotechnology that have so far been achieved in many developing countries of the world, which could safely be adopted to Nigeria include the use of:

a) Disease-free planting material (Micropropagation): a variety of tissue culture techniques are applied to propagate disease-free planting materials for many horticultural crops. In many African countries like Kenya, for example, the application of tissue culture technology has been initiated in different crops and has resulted in increased production of banana, pyrethrum, potato, coffee, cassava, sugarcane, date palm, flowers, etc. The demand for such materials is demonstrably high, and the changes at the household income levels of growers are becoming increasingly noticeable.
b) Pest resistance: Biopesticides (*Bacillus thuringensis and B. sphaericus)* are being practiced widely to reduce the use of chemical pesticides and where cultural practices are not effective. *Bacillus thuringensis* (Bt) toxin is, for example, being used by farmers in China to combat cotton bollworm where the use of chemicals and other plant protection methods can no longer reliably control the pest. This genetically modified (GM) cotton provided smallholder farmers with significant economic as well as environmental benefits, by substantially reducing pesticide use without reducing output per hectare or quality of cotton (Pray *et al.*, 2000).
c) Crop improvement/Transgenic plant varieties: This requires isolating genes that improve yield in some crops and inserting them in other crops using genetic modification technologies .The principal benefits of transgenic crops include more flexibility in crop management, decreased dependence on conventional insecticides and herbicides and higher yields. Thus, crop improvement could be promoted through the production of genetically improved plants with superior properties in terms of resistance to diseases, insect pests and abiotic stresses, Many GM plant varieties, such as virus-resistant potatoes, tomatoes, cucurbits, Bt Cotton, Bt Corn, etc. are widely planted today in different parts of the world.
d) Livestock improvement (New diagnostics and vaccines for livestock diseases): Traditional breeding practices have been too slow in Nigeria to meet national requirements of dairy products. Importing heifers and/or young quality-bred calves from abroad may be too costly and could also have adaptability problems. Cutting-edge technologies such as Marker Assisted Selection in animal biotechnology, artificial insemination, embryo transfer, in vitro fertilization, Successful gender pres-election in farm animals, etc. need to be carefully studied and introduced. Diagnostic tests and DNA vaccines have been developed for rinderpest, cowdriosis (heart water), theilerosis (East Coast Fever) and foot and mouth diseases.
e) Nutritional benefits: traditional breeding has been unsuccessful for increasing nutritional elements of many plant varieties, but recent progress in biotechnology has enabled scientists to enhance vitamin A content and elevated iron content in crops like rice (e.g. Golden Rice).
f) Reduced environmental impact: through the use of Biofertilizers (Rhizobium, Azospirllum, Cyanobacteria, etc.), Biopesticides (*Bacillus thuringensis*) and Bioremediation (cleaning the environment using different microorganisms).

Biosafety mechanisms, however, need to be strengthened whenever such technologies are to be adopted.

Biotechnology for Sustainable Industrial Growth: Lessons for Nigeria

Human activities - industrialization, urbanization, agriculture, fishing and aquaculture, forestry and silviculture as well as petroleum and mineral extraction - have profound impacts on the world's environment as well as on the quality of life. As a result, there is a growing appreciation that nationally, regionally and globally the management and utilization of natural resources need to be improved arid that the amounts of waste and pollution generated by human activity need to be reduced on a large scale. This will require a reduction and, if possible, elimination of unsustainable patterns of production and consumption. As a result, emphasis is growing on industrial sustainability because this is increasingly recognized as a key means of bringing about such reduction of environmental impacts and improving quality of life.

The World Commission on Environment and Development (Brundtland 1987) has provided insight on sustainable patterns of production and consumption through its description of sustainable development: "Sustainable Development: Strategies and actions that have the objective of meeting the needs and aspirations of the present without compromising the ability to meet those of the future ".

This definition of sustainable development can be adapted to provide a conceptual definition of industrial sustainability: Industry is sustainable when it produces goods and services in such a manner as to meet the needs and aspirations of the present without compromising the ability of future generations to meet their own needs ".
A closer look shows that industry is sustainable when it is:

- Economically viable (uses natural, financial and human capital to create value, wealth and profits).
- Environmentally compatible (uses cleaner, more eco-efficient products and processes to prevent pollution, depletion of natural resources as well as loss of biodiversity and wildlife habitat).
- Socially responsible (behaves in an ethical manner and manages the various impacts of its production through initiatives such as Responsible Care).

Developing sustainable industries implies constantly assessing and improving industrial performance. The aim is to uncouple economic growth from environmental degradation so that industry will be more profitable and, simultaneously, environmental quality will also improve.

Economic growth provides jobs and income, goods and services and opportunities to improve the standard of living for an increasing world population. Environmental protection recognizes the intrinsic value of nature and living things. It also recognizes the potential of organisms living in ecosystems to provide insights and the means for developing sustainable industrial products, processes and production systems. Sustainable industrial development can be achieved if the three requirements (economic, environmental and social) outlined above are applied to guide the pathway and shape the process by which industry and the economy grow (USDE, 1998)

At a very basic level, sustainable industrial development means doing more with less -increasing ceo-efficiency, that is, decreasing the level of pollution and at the same time the amount of energy, material and other inputs required to produce a given product or service. A major way of accomplishing this is through cleaner production. Cleaner production involves a paradigm shift where innovation is used to develop:

- Processes and production systems which:
  - Save costs and are more profitable because they are less wasteful of materials and energy (resulting In less emissions of greenhouse gases, persistent organic chemicals and other pollutants).
  - Enable greater and more efficient utilization of renewable resources (energy, chemicals and materials), lessening our dependence on non-renewable resources such as petroleum arid reducing associated greenhouse gas emissions.

- Products which are:
  - Better performing, more durable and don't persist after their useful life.
  - Less toxic, more easily recyclable and more biodegradable than their conventional counterparts,
  - Derived as much as possible from renewable resources and contribute minimally to net greenhouse gas emissions (UNEP, 1999).

Essentially, biotechnology harnesses the catalytic power of biological systems, whether by direct use of enzymes or through the use of the intricate biochemistry of whole cells and micro-organisms. Defined in this way, biotechnology encompasses everything from the technology of bread-making to that involved in the production of human insulin from a bacterium induced to take up a non-bacterial gene and produce the protein coded by that gene Its history goes back centuries in such activities as fermentation and brewing of alcohol or bread- and cheese-making. New scientific and technological advances in genetic engineering and other ways of transforming biological organisms in the 1970s revolutionized commercial possibilities, giving rise to a large number of applications with the development of new products and new techniques. The recent technological developments in genetic engineering, enzyme technology, and fermentation technology are often called “the second biotechnological revolution” (or the “new biotechnology”), the first being generally recognized as Pasteur’s revolutionary treatment and prevention of human and animal infectious diseases through immunization in the late 1880s.

New biotechnology is typically a science-led technology, in the sense that most of the inventions and process and product innovations have emerged from breakthroughs in scientific and technological research undertaken in universities, research institutes, and industrial R&D departments. It denotes a broad and heterogeneous field of applied sciences and related strategic research, encompassing several distinct technologies utilized in a wide range of industries: agriculture, pharmaceuticals, chemicals, and even weaponry are all potential beneficiaries of the advances being made.

Industries are increasingly using biotechnology to produce industrial substitutes for natural agriculture products manufactured in large quantities (and mainly exported by developing countries). Many new substances are competing with each other as viable substitutes for a particular product (foodstuffs, flavours, additives, fragrances), a trend very similar to the one encountered in new materials. The demand for new foodstuffs and pharmaceutical products (e.g. vaccines) is becoming increasingly diversified, and biotechnology is providing industry with the opportunity to abandon commodity chemicals and move into more lucrative specialty and agricultural chemicals. Older biotechnological techniques (e.g. fermentation) are themselves benefiting from additional inputs from genetic engineering and new enzymatic processes.

Bio-industry is reorganizing itself to respond to these trends: conscious of the economic stakes involved in the enormous potential markets for the new biotechnological products, many chemical, pharmaceutical, petrochemical, and industrial food corporations are creating their own research laboratories in plant biology and physiology and are investing in small venture-capital companies engaged in advanced research as well as in larger companies with R&D experience. As new products depend heavily on new and more productive processes and call for rigorous quality standards and safety tests, bio-industry is typically science- and capital-intensive and requires highly qualified staff and skilled labour.

A number of biotechnology developments are having profound technical impacts on processes and products. As with new materials, these technical changes are inducing important structural changes in the economy (OTA, 1984).

- New commercial biotechnological devices and methods of diagnosis and prevention, based on monoclonal antibodies, biosensors, and gene probes, are revolutionizing the fields of health, agriculture, and environment, permitting the extension of hitherto limited physical and chemical measurements to the potential control and regulation of complex systems in the human body, in animals, plants, the environment, and in industrial processes.
- The specificity and diversification of biotechnological products are increasing, as commodity chemicals tend to be replaced by specialty and agricultural chemicals, closer to user demands. Monoclonal antibodies can be used as ultraspecific drug vectors against specific tissue antigens, opening the way to the introduction of medicines specific to individual patients (personalized therapy). Several distinct new biotechnology products tend to compete with each other as substitutes for the same traditional product: for instance, more than eight new sweeteners compete to replace sugar.
- Biotechnology contributes to a reduction in the intensity of the use of energy and materials: the production of chemicals through enhanced fermentation or enzymatic processes, industrial purification by monoclonal antibodies, and the replacement of sugar by new compounds with dramatically superior sweetening power may be mentioned as examples of this trend. New immunodiagnostic tests based on monoclonal antibodies and gene probes, besides being rapid, specific, and easy to use, are sensitive to smaller quantities of test material and imply a dramatic reduction in the quantities of blood, urine, cells, etc., needed.

- Biotechnological processes and products present the ability to use renewable energy resources and to recover reusable or marketable by-products in the processing industry, thus increasing the productivity of all energy and materials inputs through "maximum recycling" and "minimum effluents."
- The methodologies employed in the development of new products and processes in biotechnology rely on rigorous scientific knowledge in numerous fields, thus increasing rationality and diminishing empiricism in research and industrial production through a goal-directed and systematic understanding of the processes involved. This is for instance apparent in the radical change in the paradigms of pharmacological research, which has shifted from the screening of a large number of molecules to the targeting of a suitable molecule to act upon the mechanism of a specific disease. This change in the paradigm of pharmacology, made possible by new biotechnological research instruments and products, has simplified and rationalized the process of innovation and profoundly affected the pharmaceutical industry: from being a drug supplier, it is becoming an "industry of function," i.e. a supplier of a wide range of therapeutic products, diagnostics, auxiliary materials, equipment, machines, biomedical systems, and technology. A similar evolution towards rationalization of the innovation process in industry can be expected in the agrochemical and food industries.

The bulk of biotechnology sales in terms of volume and value can be grouped in three main groups of products:

- Very high value medical products used in small quantities, like vitamins (B12), antibiotics (cephalosporin), enzymes, novel biological products (interferon, tissue plasminogen activator- TPA), or monoclonal antibodies, which are extremely expensive and whose production in commercially viable quantities has only become possible with recent genetic engineering technologies.
- Low value products that have to be sold in enormous quantities, usually produced by fermentation processes, and that generally compete against similar commodities produced by more traditional means, like ethanol, methane, isoglucose, and several effluent and waste treatment substances.
- •An intermediate group of organic chemicals, such as amino and organic acids (glutamic acid, lysine), fungal proteins used in novel foods, and bacterial cultures used as soil inoculants to protect plants from pests or to supply additional nitrogen to the roots, all of which also have to compete against other processes (Green and Yoxen, 1990). Biotechnology inventions and innovations have already been applied in numerous industrial sectors.

- Food And Agricultural Production: The potential of biotechnology for increasing agricultural productivity is high, in terms of both increasing the yields of cultivated plants and of obtaining foodstuffs with higher nutritional value. Many foodstuffs are produced by fermentation, and enzymes are now widely used as processing aids in food manufacturing. Acetone, citric acid, ethanol, and other chemicals are, or have been, produced industrially by fermentation. The digestion of wastes anaerobically is not only part of sewage treatment but also a way of generating methane gas as a source of energy. Biotechnology offers ways of improving even traditional fermentations like the production of silage, a fermented gas product used as cattle feed: microbial cultures are available that ensure that the correct sort of fermentation takes place. It is expected that by the year 2000, five-sixths of the annual increase in agricultural production in the world will be due to new biotechnology and other yield increases, while only one sixth will result from the increase in the area of land used in production]. In the next century, about 75 per cent of all major seeds may be developed by genetic engineering or tissue culture (OECD, 1990).

Many developing countries have established programmes to incorporate biotechnology into agricultural and agro-industrial activities. Some have already successfully applied biotechnology to their production of palm coconut oil, eliminating major disease traits and thereby increasing productivity by about 30 per cent. A marked increase in production, using cloning techniques to enable the propagation of high-yielding varieties of oil-palms and cocos, would make it possible to improve the fat content of diets and thus cover the additional nutritional needs of growing populations. But the production of oil-palm and coca clones using tissue culture techniques, where the applications could benefit millions of small landholders in developing countries whose standard of living depends entirely on the productivity of their holdings and whose cultivation techniques would have to be adapted to the properties of the new clones, constitutes a break through that cannot be fully exploited before the end of the century (Sasson, 1988).

Wood exports play an important role in the economy of many tropical developing countries. The in vitro micropropagation of forest tree species for their wood or paper pulp is therefore of great economic interest; this technique is for instance being studied for the large-scale production of clones of several eucalyptus species with better resistance to cold weather and greater wood yield. Similarly, the multiplication and exploitation of drought-resistant plant species of commercial interest could afford useful outlets for a number of developing countries located in arid or semi-arid zones. For instance the jojoba, cultivated today in all five continents, can tolerate temperatures up to 50 C and its roots can search for water at a depth of 30 metros. It offers the possibility of controlling desertification by fixing soils and of earning a good income from valuable oil extracted from its seeds, thus bringing employment to the rural areas and the chance to export a multi-purpose product with a high potential demand on the world market. Jojoba oil can be used industrially as an excellent transmission fluid or lubricant for fast rotating machines under high pressures and high temperatures (replacing the strategic sperm whale oil and thus limiting the massacre of sperm whale and other cetacean populations), as a shampoo and a sun cream in the cosmetics industry, as a treatment for skin diseases and bums in the pharmaceutical industry, as a wax to replace other plant or animal waxes, and meal proteins could be extracted from it for use in animal feed (Sasson, 1988).

Tissue culture techniques have been applied to rice, maize, wheat, barley, cabbage, lettuce, tomatoes, peas, onions, potatoes, rapeseed, tobacco, sugar cane, and cotton for such purposes as gene transfer for disease resistance and salinity tolerance, selection of plants resistant to pathogens, and recovery of immature embryos from defective seeds. Substantial research in biotechnology and genetic resources has led to the adoption of genetic selection and breeding techniques by several countries, as well as to the improvement and production of local varieties of crops with higher yields, greater pest resistance, and earlier maturation. Progress in fermentation technology for the production of feed components, single-cell protein and industrial chemicals, as well as recent developments in enzyme technology for the production of antibiotics are expected to have a large impact on industry and agriculture in several developing countries. Nitrogen-fixing biotechnology, which enables non-leguminous crop plants to fix atmospheric nitrogen should permit a two to fourfold increase in corn yields.

- Livestock Husbandry And Animal Health: Genetic engineering is already being applied in animal husbandry. Bovine embryo transfer techniques can have great zootechnical and economic advantages. Besides helping to speed up the improvement process or the preservation of superior breeds showing special characteristics (for instance, better resistance to tropical bovine diseases), embryo transfer can increase the production of meat and milk, each inseminated cow being able to give birth to up to 20 calves per year. The development of DNA probes can permit the sexing of the bovine embryos to be transplanted, thus selecting male embryos for meat production and female embryos for milk production. In some developing countries this technique could help overcome chronic milk shortages.

Genetic engineering also provides the possibility of developing and producing large quantities of new vaccines against many cattle, swine, and poultry infectious diseases that plague developing countries, like aphthous fever, theileriasis, hog cholera, colibacillus and viral diarrhoea, pseudo-rabies, coccidiosis, fowl pest, etc. Traditional vaccines against the aphthous fever virus, which is endemic in large areas in developing countries, are prepared by inactivation or attenuation of virus strains obtained from material collected from the lesions themselves, and imply the manipulation of very large quantities of virulent virus; in addition, these vaccines are unstable and must be stored under refrigeration, which is not always easy in tropical countries. The production by rDNA techniques of an effective, safe, and heat-stable vaccine against this disease will have a great economic impact in developing countries, which will be able to vaccinate their herds systematically and to increase the export of their livestock products to disease-free industrialized countries.

Fowl pest is the principal virus disease of poultry in the world, and it has devastating economic effects in several developing countries, where poultry meat and eggs form a major contribution to the human diet; most of the commonly used vaccines are relatively ineffective and must be administered on several occasions in high doses, a task rendered very difficult, particularly in countries where village poultry and small flocks predominate. A new, simple, and cheap vaccine is needed; research in genetic engineering may permit the production of massive quantities of antigen to be used for the preparation of an improved vaccine, in terms of potency and geographical utility (Sasson, 1988).

- Pharmaceutical And Chemical Processing: Biotechnology has been efficiently used to produce new pharmaceutical products, such as interferon, growth hormone, lymphocytes, and tissue plasminogen activators. Biosynthesis of growth hormones of the main livestock species by genetically engineered micro-

- organisms can markedly improve their productivity and would have significant effects in intensive livestock husbandry. Bovine growth hormone can increase milk production by 20 per cent at the same feed costs.

- Medical Treatment: The health care sector has attracted the most early interest for various reasons. Health care covers a large number of human activities, ranging from "formal' care provided by organized health services (clinics, hospitals, and other organizations for care, cure, or preventive medicine), "alternative" medical practitioners and self-medication or self-diagnosis products, to unpaid care of the sick and infirm. Biotechnology is particularly applicable to health care products in all these activities, including pharmaceuticals, vaccines, and diagnostic kits. It also provides ways of more rapidly screening potential pharmaceuticals, speeding up and lowering the high cost of pharmaceutical innovation.

Genetic engineering offers a way of producing on a larger scale biological molecule with therapeutic value that were formerly very scarce and therefore expensive, if available at all. Examples of these substances would include the first product of rDNA organisms for human therapy, human insulin, as well as human growth hormone, the interferons, interleukin, and other bioactive proteins. Many higher plants possess active compounds that form the starting material for a large range of drugs. The 1986 market for plant-derived pharmaceuticals was estimated at US$9 billion in the United States alone. Tropical developing countries, whose pharmacopoeia is very rich and which constitute the main exporters of plant medicinal raw materials, could start from naturally occurring compounds and resort to biotechnology to isolate them and produce novel pharmaceuticals, thus reducing current imports. In addition, the amount of active product required for pharmaceutical uses of these substances is usually low and the pay-off potentially huge in many instances; however, the regulations concerning the commercialization of medicines apply equally to plant medicinal products, and since most therapeutic substances require painstaking testing, development may often be a lengthy and expensive process (Flores *et al.*, 1987).

By contrast, a large number of new methods of testing human fluids and infections have been developed, based on monoclonal antibody technology. The fastest growing diagnostics markets are in immunology and microbiology. Monoclonal antibodies used in diagnostic kits offer products that, because they are not ingested by or applied to people, could be brought quickly to market and for which there is growing demand. Already, monoclonal antibody-based tests sold in pharmacies for confirming pregnancy are being established as a do-it-yourself market, and other over the-counter products are being introduced for monitoring fertility. Monoclonal antibody products are also becoming a vital part of the growth of new types of imaging techniques, and accurate, rapid, and cheap tests based on DNA probes and biosensors are promising future developments (Green and Yoxen, 1990).

The cost of the techniques involved are falling sharply, so that they are likely to become, with the improvement of current vaccines and the development of effective, safer, and cheaper new vaccines, the major instruments of public health policy in developing countries.

Recombinant DNA techniques can be used to produce large quantities of immunogenic proteins synthesized by genetically engineered microorganisms, which are the basis for effective new vaccines. A genetically engineered vaccine requires no inactivation procedure as conventional vaccines do, facilitating its administration and reducing cost; additional economies may arise from the replacement of expensive embryo culture systems by relatively simple conventional bacterial media, from savings on high- security plants usually required in the production of conventional infectious disease vaccines, from reduced transport and storage costs, and from reduced testing, since the vaccines do not contain the disease-producing pathogen. Recombinant DNA techniques are being developed for the production of vaccines against viral hepatitis B (highly endemic in regions of Africa, Asia, and South America), rabies (a serious health problem in developing countries and still a cause of high mortality in domestic livestock), herpes, cholera, leprosy, malaria (the most widespread human infectious disease), schistosomiasis (chronic throughout tropical countries), onchocerciasis, sleeping sickness, and Chagas' disease.

Lessons

It is possible to draw a number of general conclusions from the above

i) The application of biotechnology in a wide range of industry sectors (chemicals, plastics, food processing, natural fibre processing, mining and energy) has invariably led to both economic and environmental benefits via processes that are less costly and more environmentally friendly than the conventional processes they replace. In effect, the application of biotechnology has contributed to an uncoupling of economic growth from environmental impacts.

ii) The application of biotechnology to increase the eco-efficiency of industrial products and processes can provide a basis for moving a broad range of industries toward more sustainable production. To achieve this, further development of biotechnology and supporting technologies will be needed, as well as policies that provide incentives for achieving more sustainable production.

iii) The main driving forces for adoption of more efficient bioprocesses and bio-products are cost savings and improved product quality/performance. Environmental considerations were (in the case studies, at least) an important but secondary driving force.

iv) Successful biotechnology/bioprocess development requires effective management of technology development by companies and use of tools that assess both the economic and environmental performance of technology during its development. There is a need for improved assessment tools that are easier to use and at earlier stages of the technology development process.

v) Even large companies may not have in-house all the expertise required to develop more efficient bio-products and bioprocesses. Collaboration with university and government researchers and other companies is an important contributing factor for successful introduction of these products and processes.

vi) Long lead times are often required for introduction of 'paradigm shift' technology into a company: but development times can be reduced considerably in subsequent development cycles.

vii) The application of biotechnology for developing industrial products and processes is still in its infancy. As awareness builds and the technology continues to be developed and diffused through different industry sectors over the next few decades, the economic and environmental benefits are predicted to grow.

CONCLUSION

Agricultural biotechnology, including tissue culture, DNA-marker assisted breeding and GM technology, has the potential to increase crop productivity and food security in Nigeria and developing countries. This could be achieved through the development of improved varieties, with increased yields, nutritional content and storage characteristics. It provides tools for adopting and modifying the biological organisms, processes, products found in nature. It provides tools for industry to continue improving lost and environmental performance beyond what could be achieved using conventional chemical technologies. Biotechnology has the potential significantly contribute to economics of developing countries across a wide range of industry sectors, including agriculture health, environmental management and manufacturing. It is therefore crucial that the development of biotechnology takes place within a framework of best practice, international standards and safeguards.

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