KEEPING HUNGER AT BAY
Agricultural Biotechnology and Food Production in Sub-Saharan Africa

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Abstract

Persistent famine in Sub-Saharan Africa has brought to the African political arena the debate about the potential contributions of modern biotechnology in improving agricultural production and increasing food security. The international debate, which has largely focused on risks and benefits of genetically modified organisms, had been confined to scientific and policy circles between the United States of America (USA) and Europe. It has centered on concerns such as potential impacts of genetically modified organisms on the natural environment, food safety and associated human health considerations, animal welfare, role of private companies and their hegemony in the biotechnology industry, and the distribution of benefits from global investment in the development of the technology. In Sub-Saharan Africa this debate is relatively new and not part of serious policy and diplomatic dialogue although it is acquiring the attention of politicians in some countries of the region. It is also not really informed by the region's own scientific endeavors and economic aspirations as well as the experiences of other developing regions of the world.

The participation of African countries in the ongoing debate on the benefits and risks of genetically modified products should be influenced and informed by their own aspirations, needs and perceptions of this technology. It should evolve as these countries gain a better understanding of the technology, and as their R&D efforts generate new products and processes, and as they experiment with biosafety regulations to assess and manage risks. What is of concern is that the growing uncertainty and anxiety over GMO products in Europe may undermine their current investments in R&D. Again the challenge is one of building regulatory measures and capability that promote investment in the technology while ensuring that science-based risk assessment form the basis for decision-making.

This paper argues that in the absence of public constituencies that are informed of the pervasive nature of modern biotechnology and without science institutions that are prepared to effectively engage in the economic sphere, Sub-Saharan Africa is unlikely to respond to rapid new bio-scientific and technological advances. The region will not be able to manage the technology—its development and application. Emphasis of the paper is on *how* and not *whether* modern biotechnology can contribute to the improvement of Africa's agricultural and enlargement of prospects of food security. It is an attempt to focus the debate on the conditions under which Sub-Saharan Africa can harness biotechnology, particularly genetic engineering, to break some of the barriers to increasing food production.

INTRODUCTION

Recent scientific and technical advances in biotechnology are increasing humanity's ability to produce more and better quality food, manage environmental change and improve health. They are improving our understanding of the genetic foundations of living organisms. In agriculture, new technical opportunities of improving the quality of crops and livestock are being generated as the science associated with biotechnology grows. Marker assisted selection and genetic mapping make it now relatively easy to select and transfer single genes from one plant to another with high precision. New diagnostic tools and vaccines are now being developed and used to diagnose and control livestock diseases. Many of these technological developments take place in the developed and a few developing countries at a time when Sub-Saharan Africa experiences high levels of food insecurity and increasing socio-economic instability.

Agricultural biotechnology has developed in just about 15 years to become a big industry with a multi-million dollar investment across the globe. During this period a substantive number of scientific and technical breakthroughs have been made in genetic engineering. The first genetically modified agricultural biotechnology product entered the market in 1994 and by 2001 more than 50 genetic modifications involving at least 12 crops had been approved and cultivated on more than 50 million hectares in at least 12 countries. The United States of America is the world's leader in both research and commercialization of genetically modified crops and other agricultural biotechnology products.

For Sub-Saharan Africa benefits from the adoption and development of modern biotechnology will come with specific policy and institutional measures that countries of the region, collectively and individually, put in place to ensure that their scientific and technological capabilities to engage in R&D and to monitor and assess risks of genetic engineering. Continued reliance on positions of either the USA and European Union (or both) sold to them through diplomatic channels will at best keep them passive players in international biotechnology management, and at worst will deny them the opportunity to harness and apply the technology for food production while managing any risks of genetically modified organisms. Sub-Saharan Africa's problems and immediate economic needs are different from the USA and European Union. The context of the Atlantic debate and associated tensions on genetically modified organisms do not articulate Sub-Saharan Africa's food and economic production needs and aspirations.

The growing debate about the impacts of genetically modified foods and the solution to the increasing famine in Southern Africa has stimulated public awareness in Africa about some of the intricate issues associated with the development and application of modern biotechnology. It has also moved the transatlantic tensions over trade in genetically modified organisms onto the African landscape. The controversy about genetically modified food aid in Zambia and Zimbabwe is largely an extension of the Europe-USA tensions. While farmers and governments in Europe have expressed serious concerns about the safety of genetically modified foods to human health and the environment, in the USA the development and application of genetically modified food is growing. More acreage of US land is being devoted to the cultivation of genetically modified crops for export. Environmental activists and consumer groups have organized demonstrations, filed lawsuits and destroyed field test sites in Europe. What some analysts treated as a concern of Europe and the USA is starting to get high on the agenda of public policy and political agendas of African countries. The controversy is getting to the local levels of governance in such countries as Zambia, South Africa, Zimbabwe and Malawi. But public awareness of the nature and impacts of agricultural biotechnology as a system of techniques generating a wide range of products and processes is still very limited.

Recent studies show that developing countries that establish the necessary scientific infrastructure and institute conducive regulatory measures are becoming the major producers of agricultural biotechnology products. The challenge is that of managing technological change. The evolution and development of biotechnology are not deterministic. Countries can govern developments in agricultural biotechnology to achieve their economic, environmental and social aspirations.

The goal of this paper is to increase awareness of the critical issues that should be at the center of public debate about the role of agricultural biotechnology in Africa's sustainable development. It explores options for new programmatic approaches to improving the quality of national R&D and related policies. Our emphasis here is on conditions that are necessary for Sub-Sahara African countries to build the requisite scientific and technological competencies to engage effectively in the development and application of modern biotechnology to improve food production. The paper eschews the old discussion on what the technology can or cannot do for Africa and turns our attention to *how* Africa can harness the technology and associated scientific developments to increase food production. It is written to inform African policy makers on ways and means of ensuring that biotechnology—its development and application—enlarge the base of food security without undermining human health and environmental integrity.

The first section of the paper focuses on international trends in modern agricultural biotechnology. It maps out the technology's evolution and overview of global acreage and distribution of genetically modified crops. This section also provides an overview of policy issues associated with the regulation of biotechnology. It argues that much of the current debate about genetically modified organisms fails to unpack many of the crucial science policy issues associated with the management of modern biotechnology and is also based on limited understanding of the nature of the technology. The tendency is to reduce a whole technological system to a small category of its products ignoring many process technologies.

The second section is an overview of the status of agricultural biotechnology in Sub-Saharan Africa. This section describes current efforts of some of the African countries and provides an identification of their strengths, constraints and national policies to promote the technology's development and application.The third section focuses on public policy issues for safe development and application of biotechnology in Africa. Emphasis is placed on those activities that would enlarge the knowledge and information base for public policy making in Africa.

1. AGRICULTURE AND FOOD PRODUCTION IN SUB-SAHARAN AFRICA

1.1 Trends and Challenges

Africa's economies are heavily dependent on agriculture. Agriculture contributes to more than 30 percent of Gross Domestic Product (GDP) of most countries and employs at least 45 percent of the continent's 850 million people. However, the sector's performance has been poor in three decades or so. Sub-Saharan Africa is the only region where agricultural output has fallen behind population growth for most part of the last three decades. The region's food demand has been expanding at an annual rate of 3.1% since the mid-1980s. Its agricultural performance weakened considerably in 2000. Overall agricultural production fell by 0.3 percent having increased by about 1.9 percent in 1999. Eastern Africa saw agricultural output fall by 0.5 percent in 2000. It declined by 1 percent in central Africa while in the Sahelian countries cereal production fell by almost 13 percent in that year. Western Africa experienced sluggish or slow growth of the agricultural sector. In southern Africa (excluding South Africa), agricultural production fell by 3.3 percent in 2000 after increasing by 14.2 percent in 1999. Crop and livestock production fell by 3 and 3.9 percent, respectively.

According to recent estimates by the United Nations Food and Agriculture Organization (FAO), agricultural production is estimated to fall more drastically in Eastern and Southern Africa in 2001 and 2002.

> In several parts of southern Africa, the reduced 2001 maize harvest, caused by adverse weather, has led to food shortages. In Malawi, food shortages have emerged in southern parts, where floods affected more than 600 000 people. In Zambia, emergency food aid is required for almost 1.3 million people following the poor 2001 maize harvest. In Zimbabwe, the 2001 maize output declined by 28 percent from the level of the previous year, resulting in food shortages in several areas. …. In Angola, emergency food aid is needed for over 1.3 million internally displaced people. …
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> In eastern Africa, some 18 million people still rely on food assistance because of the lingering effects of last year's drought, coupled with conflict in some parts. The situation is particularly severe in Eritrea, Ethiopia, Kenya and the Sudan, where recent droughts have sharply reduced food production and killed large numbers of livestock.

Africa is now the largest recipient of food aid. Approximately 1.3 million people in Eritrea, 5.2 million in Ethiopia, 1.5 million in Kenya and 2 million in Sudan require emergence food aid in 2002. In Southern Africa emergence food assistance is required by at least 14 million people. Food security assessments conducted by the World Food Programme (WFP) in September 2002 showed that more than 70 percent of households in Malawi and Zambia had no cereal seed while in Zimbabwe more than 94 percent of farmers were without seeds. In Angola, the number of people in need of emergency food aid has increased to 1.9 million from 1.42 million.

The decline in agricultural output corresponds relatively well to increasing food insecurity in Sub-Saharan Africa. It is estimated that about 200 million people in Africa are chronically hungry and nearly 30 million require emergency food and agricultural assistance in any year. The region has at least 25 percent of the world’s undernourished people. Millions of Africans, particularly children under the age of 6 years, die every year as a result of hunger. Many suffer from one or more forms of malnutrition, including protein-energy malnutrition (PEM) and a lack of micronutrients. The most vulnerable are pre-schoolchildren and pregnant women. Between 1980 and 2000, the prevalence of PEM among children rose by 2.3 percent. PEM deficiency is manifested in stunting and causes poor cognitive development and low educational achievement.

The causes of declining agricultural production and increasing food insecurity[1] in Sub-Saharan Africa are many, interrelated and complex. They have socio-political, economic, environmental and technological variables. Food insecurity is not simply caused by failure of agriculture to produce enough food, but also by many structural inadequacies that make it difficult for households to have access to food. Indeed food security is much about ensuring that individuals have access to sufficient food at the household level.

Demand for and accessibility to food are influenced by a variety of factors, including income levels, population growth and movements, infrastructure, lifestyles and preferences, and human resource development. Increase in population is likely to stimulate increased demand for food. People's access to food is largely determined by income. In Sub-Saharan Africa where most people have less than US$ 1 per day to live on, many do not have access to basic food.

To meet increasing demand for food and enlarge the basis for food security, productivity increases will be required. This is will not be through expansion of cultivated area but mainly on the basis of improvements in crop yields. If the gap between population growth and food demand is to be closed, much greater attention must be put on measures that will improve the region's ability to harness and apply new scientific and technological advances. In addition, economic policy reforms, social and political stability and improvement of infrastructure, particularly roads will contribute to the enhancement of food security.

1.2 Agricultural Research Systems and Related Technological Imperatives

Many of today's national agricultural research systems in Sub-Saharan Africa were established more than five decades ago by colonial governments. Their orientation and organization are still geared to the imperatives of those times. They were configured to engage in the development and application of chemical fertilizers, use of mechanized farm machinery and the application of herbicides. Plant breeding stations and botanic gardens were set up to develop and/or enhance crop varieties. These institutions are largely public with the express mandate of conducting research to generate public goods. Their main orientation, at least during the colonial era, has been to ensure adequate supply of tropical export crops.

The organization of research was largely influenced by two cultures: British and French. In the British colonies a two-tiered system of agricultural research was instituted. Regional research agencies were established to conduct basic research as well as research on specific export commodities such as coffee while those in the United Kingdom itself were dedicated to applied research. In the French colonies, only satellite research stations were established while the main research was conducted in centralized institutions headquartered and managed in France. This is

[1] We define food insecurity as the lack of access to adequate food to maintain an active healthy life.

in contrast to the British system that was largely decentralized.

In the Anglophone Africa the agricultural research institutions and their administrative control were ceded to the new independent governments. In contrast, France continued to manage and fund most of the agricultural research in her former colonies. In most cases France continued to provide scientists and technicians while support staff were provided by the former colonies. But in both cases, post colonial agricultural research in Sub-Saharan has continued to focus export crops. Scientific and technological capabilities to play this role were accumulated by some of these institutions.

The number of agronomists, plant breeders, geneticists and agricultural engineers grew considerably in many Sub-Saharan African countries. According the International Service for National Agricultural Research (ISNAR), the number of scientists in agricultural research institutions in Sub-Saharan Africa grew at least fourfold in the past three decades. Their levels of training also increased markedly and now many of the agricultural research institutions are largely staffed by national rather than expatriates.[2]

These institutional developments have generated major breakthroughs in agricultural research. Scientific and technological advances in plant breeding have contributed to yield increases and considerable improvement of agricultural production in some countries of the region. However, during the past three decades agricultural research infrastructure and capability of many countries of Africa has deteriorated and in some cases collapsed. For example, it collapsed in the Democratic Republic of Congo after Belgian expatriates left in the 1970s. National agricultural research expenditures have declined in most countries of the region. Limited research is now being conducted on such staple crops as cassava, millet and sorghum.

The evolution of agricultural research in the region has also been associated with technological changes. In particular, the national agricultural research institutions have been at the front of developing and transferring technologies associated with the Green Revolution. In some parts of Africa, these technologies have contributed to increases in crop yield. However, on the whole they have not made the region to be food secure.

> During the 20th century, conventional breeding produced a vast number of varieties and hybrids that contributed immensely to higher grain yield, stability of harvests, and farm income. Despite the successes of the Green Revolution, the battle to ensure food security for hundreds of millions

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2 Pardey, P et. al 2002. 'Agricultural Research in Africa: Three Decades of Development'. ISNAR *Briefing Paper* 19r.

> miserably poor people is far from won. Mushrooming populations, changing demographics, and inadequate poverty intervention programs have eroded many of the gains of the Green Revolution is over. Increases in crop management productivity can be made all along the line: in tillage, water use, fertilization, weed and pest control, and harvesting. However, for the genetic improvement of food crops to continue at a pace sufficient to meet the needs of the 8.3 billion people projected to be on this planet at the end of the quarter century, both conventional technology and biotechnology are needed.[3]

The ‘Green Revolution’ benefits are unevenly distributed. While large parts of Asia have achieved high levels of food security, Sub-Saharan Africa has seen the converse: declining food production and increasing malnutrition.

Sub-Saharan Africa is now confronted with major crop and livestock production challenges. For example, livestock production has fallen considerably because of infestation by such diseases as the Tsetse-transmitted African animal trypanosomiasis. It infests 37 percent of the continent, and affects more than 20 countries. The disease leads to loss of productivity in animals and, without treatment, is frequently fatal. Large areas of land are today left with relatively few cattle because of the presence of the tsetse fly, and the estimated losses in agricultural output and productivity are very significant.

Cassava one of the most important crops in the fight against hunger in Sub-Saharan Africa is a victim of bacterial and viral diseases, insect pests, weeds, and drought. In Africa, average cassava yield is 8 tonnes per hectare compared to potential yields of over 80 tonnes per hectare. Attempts by farmers to market their cassava products have also fallen well short of their potential, because of rapid post-harvest deterioration and inadequate starch and protein content in the roots. Conventional breeding efforts have attempted to address many of the constraints facing cassava productivity, but with limited success. Progress is slow because of the crop's complex genetic makeup.

Modern agricultural biotechnology is one of the new technological tools that countries of Sub-Saharan Africa should harness to effectively confront many of the challenges of crop and livestock production. It promises to change current agricultural production practices and related management systems. Development of crops genetically engineered to resist certain insect pests and withstand harsh environmental conditions is poised to significantly reduce the use of

[3] Borlaug, N. 2000. ‘Ending World Hunger: The Promise of Biotechnology and the Threat of Antiscience Zealotry’ in *Plant Physiology*, October 2000., Volume 124, p. 487. www.plantphysiol.org

chemical insecticides. Herbicide-tolerant crops will allow the adoption of conservation tillage practices with environmental benefits. Additional promises are seen for the future in protecting and restoring the environment. Increased knowledge of plant and microbial metabolism and genomes was seen as leading to the production of plants and other organisms with enhanced ability for bioremediation of contaminated soils and water. Plants that need fewer external inputs (especially those that are environmentally damaging) are likely to emerge from genetic engineering.[4]

2. AGRICULTURAL BIOTECHNOLOGY: GLOBAL TRENDS AND POLICY ISSUES

2.1 Evolution and Scope of Agricultural Biotechnology

Modern agricultural biotechnology has its antecedent in scientific discoveries of the 1970s. Scientific discoveries in such areas as molecular biology, biochemistry and microbiology formed the foundation for the technology's emergence and growth into a mature industry. The development of the recombinant DNA (r-DNA) technology by scientists at Stanford and University of California in 1973 revolutionized science. It opened a wide range of possibilities of identifying, isolating, selecting and transferring genes from one organism into another. Essentially, "genetic information contained in a gene of a cell of one organism is isolated, taken out of that organism, and placed in the chromosome of a cell (or cells) of another organism. The resulting DNA in the recipient cell contains both its own original, naturally occurring genes and the new gene. …the characteristic encoded in the foreign gene will be manifested, or "expressed", in the recipient cell…."[5] These developments have irreversibly changed agricultural research. They have enlarged capabilities of scientists to uncover a large body of information about the genetic makeup and functioning of plants, animals and microorganisms.

The 1990s witnessed a new wave of scientific advances in biotechnology. The mapping and sequencing of the human genome have given rise to a new scientific enterprise: genomics. Genomics is "the development and application of research tools that uncover and analyze

[4] Weeks, D. *et. al*. Ed. 1999. *World Food Security and Sustainability: The Impacts of Biotechnology and Industrial Consolidation*, p. 17. National Agricultural Biotechnology Council, New York.

[5] Avramovic, M. 1996. *An Affordable Development? Biotechnology, Economics and the Implications for the Third World*, p. 9. Zed Books, London.

thousands of different molecules at a time."[6] It has granted scientists an unprecedented access to the molecules of life. Through it massive amounts of biological information can be converted into electronic form, linking life sciences to information sciences. The science of genomics and associated techniques enable scientists to simultaneously analyze the identity and function of tens of thousands of different genes. It has considerably increased the speed and scale with which genomes of organisms are sequenced and functionally analyzed. Agricultural genomics is making it relatively easy for scientists and companies to identify genes that are linked to particular agronomic traits and diseases. They are able to develop genetic sequences that are able to facilitate the expression of certain traits and prevention of certain diseases. Combined with conventional plant breeding, scientists will be able to use genomic techniques to develop new varieties of crops with desired traits.

Agricultural genomics research is underway for a range of plants and crops. DNA sequencing of rich is at an advanced stage. A majority of genes in rice genomes have been identified and sequenced. The potential of agricultural genomics is increasingly being recognized by governments and private industry. This is manifested in the financial resources being invested in R&D. For example, in 1999 the US government allocated at least US$ 40 million to fund genomics research on crops of national importance. Several major agricultural genomics initiatives have been established to determine the sequence and functionality of several cereal crop genomes. They include the International Rice Genome Initiative, the Japanese Government Rice Genome Project, the US National Corn Genome Initiative and the International Triticeae Mapping Initiative.

Related to genomics is proteomics—the study of how proteins are made, their identification and functioning in the cell—is set to be next frontier science in this millennium. It holds promise of potentially lifesaving medical treatments. This science enables scientists to uncover information on how genes are related to biological functions and diseases. Clinical proteomics is revolutionizing the development of biomarkers for drug development. A protein floating in blood can help predict a disease.[7]

6 Zweiger, G., 2001. *Transducing the Genome: Information, Anarchy, and the Revolution in Biomedical Sciences*, p.xii. McGraw-Hill, New York.

7 New York Academy of Sciences, *Academy Update*, March/April 2001.

Another major technological development is associated with increased scientific understanding and use of molecular marker technology.[8] Molecular markers can now be used to select specific genetic information at the DNA level. They are also used in studies of genetic diversity and taxonomic relationships between plant species as well as in studies of biological processes such as pollen movement and of genetic mechanisms behind physiological traits.

These scientific and technological developments have irreversibly changed agriculture. Agricultural biotechnology has in no small measure enlarged the ability of society to produce higher quality food in environments that were perceived of as of low or no productive potential. It is now possible to cultivate tropical crops in temperate zones. New varieties resistant to such ecological phenomena as drought have been developed through biotechnological techniques. In the livestock sector the development of diagnostics and a variety of other tools is broadening the scope and ability to manage animal diseases that were until very recently considered as incurable.

The stock of basic and applied scientific knowledge in the field of agricultural biotechnology has grown rapidly in the past decade or so. The capacity of countries, particularly the industrialized ones, to engage in related research and development has also grown considerably making it possible to commercially exploit the technology. In fact today agricultural biotechnology is one of the fastest growing knowledge industries in the world.

However, the development and application of modern agricultural biotechnology are characterized by uncertainty. There is uncertainty about socio-economic, health and environmental benefits and risks from the technology. Public debate and anxiety on the potential negative environmental, economic and human health impacts that some of the products and processes of biotechnology have intensified in the past decade or so. This has been so mainly because of the limited scientific knowledge on the nature of risks. Indeed, while the pool of scientific knowledge of how to develop and apply biotechnology products has grown, our understanding of any risks it poses, from a scientific basis, is still meager.

There is also uncertainty about the ability of developing countries to participate in the agricultural biotechnology revolution. Some of the uncertainty has largely been stimulated by claims that the technology is suited to the needs and conditions of the rich in the economies of

[8] Molecular markers are identifiable DNA sequences found at specific points of the genome. They differ between individuals of the same population.

the West.[9] Its appropriateness to the developing countries has been questioned. The attention on this issue—whether the technology is appropriate or inappropriate to developing countries—has been clouded with conventional thinking of the process of technological change as linear. The linear view of technological change essentially advocates that countries take a step-by-step entry into a technology. They have to start from traditional then move into conventional technologies before they engage in the development and application of radical and modern technologies. This thinking simplistic in so far as it ignores the fact that countries can leapfrog into new more sophisticated waves of the technology.

Modern agricultural biotechnology is pervasive in the sense that impacts spread across various industries (ranging from pharmaceuticals to agriculture) and socioeconomic groups. It is also multidisciplinary in nature. It encompasses various techniques that are used in an integrated way. Particular biotechnological techniques can be applied across a wide range of sectors and, therefore, different actors with different economic and social interests are involved. This not only raises the feature of complexity inherent in the process of technical change but also determines, again, the nature and levels of investment in R&D.

The development and commercialization of agricultural biotechnology are also characterized by growing complexity associated with the growing number of agents with diverse and sometimes conflicting interests. This diversity of agents makes biotechnology a complex industry. Firms' and countries' entry and performance in this technological areas are determined by factors such as prior accumulated knowledge and experience in similar technological areas, and technical and financial flexibility to manage the high scientific intensity associated with the technology.

2.2 Institutional and Economic Concentration of Agricultural Biotechnology

The emergence and development of agricultural biotechnology have been associated with the emergence of a variety of institutional arrangements for R&D, regulation and commercialization. The technology's rapid development has stimulated various patterns of institutional change and formation. In some cases the rapid scientific and technological advances have exerted considerable pressure on some of the institutional arrangements necessitating various organizational reforms and the creation of new institutions. For example, advances in genetic

[9] Bunders, J. ed. 1990. *Biotechnology for Small-Scale Farmers in Developing Countries*. VU University

engineering have destabilized the traditional disciplinary organization of public R&D and stimulated radical reconfiguration of public agricultural laboratories in the industrialized and some of the industrializing countries.[10]

Many major and sometimes radical institutional changes have been witnessed in the corporate domain. It is in this sphere where a diverse range of institutional arrangements for agricultural biotechnology have emerged and grown rapidly. In fact a large share of agricultural biotechnology R&D is now in the corporate domain. In general, three categories of private companies have been responsible for the rapid growth of agricultural biotechnology. In the first category are those companies that had already accumulated substantial capabilities in second-generation biotechnology, i.e. in fermentation and products like antibiotics, vaccines and enzymes. The second category is those companies that were specifically created to engage in modern biotechnology and had to build capabilities in such areas as genetic engineering. The last category comprises of those companies that had no prior engagement in biotechnology but perceived the potential of the technology and were willing to invest in its development, sometimes with the aim of diversifying their products. These three categories of companies have played a major role in the development of agricultural biotechnology although their strategies and levels of engagement varied across sectors, countries and time. What is however common to all of them is that each had direct association with university R&D. The companies that were created to deliberately engage in the technology were in fact born out of university departments by university professors.[11] The other categories of firms relied on universities as sources of scientific knowledge and information. For example, the traditional non-biotechnology companies contracted universities to develop for them basic scientific information and principles in genetic engineering.

According to Ernst & Young, in 1997 US companies invested $9.4 billion in R&D, employed 140,000 people and posted total revenues of $18 billion. At the same time there were 1,036 European companies working in the life sciences, employing more than 39,000 people directly, with revenues of $3.1 billion and $2.2 billion invested in R&D.[12] Private agricultural R&D

Press, Amsterdam.

10 Clark, N. and Juma, C. 1991. *Biotechnology for Sustainable Development: Policy Options for Developing Countries*. ACTS Press, Nairobi.

11 Kenny, M. 1986. Biotechnology: The University-Industrial Complex. Yale University Press, New Haven and London, and Avramovic, M. 1996. *An Affordable Development? Biotechnology, Economics and the Implications for the Third World*. Zed Books, London.

12 Ernest and Young, 1998.

expenditures grew from $3.9 billion in 1981 to more than $7 billion in 1993. In 1999 Monsanto alone allocated some $1.2 billion for biotechnology research while the National Institutes of Health allocated $15.6 billion in 1999 for basic bioscience research. In contrast the CGIAR[13], the largest public spender in the same area spends around $370/ann. only 7% of which is on biotechnology.[14] In 2000 there were more than 1350 biotechnology companies in the world. Their total sale of products was estimated at US$13.7 billion.

The considerable growth in market sales of agricultural biotechnology products and processes is accounted for by *inter alia* the following factors. *First*, the scientific information base for the development and application of agricultural products and services has been enlarged enormously in the past five years. Science in such areas as recombinant DNA has grown. Knowledge about genetic structures and functions of plants and livestock is growing rapidly making it possible to exploit a wide range of undiscovered and under-utilized traits in plants and animals. For example, genes that determine ripening of tomatoes have been identified making it possible to regulate the shelf life of tomatoes.

National and international public research organizations are also key players in biotechnology R&D. In Western Europe, Japan and the US the mid-1980s saw the emerging of biotechnology programmes to foster national competitiveness in the development and application of the technology. These programmes were established and managed in national public agencies responsible for research in agriculture, environment, mining and human health. Cross-sectoral committees were formed to ensure that there was coherence and synergy in national biotechnology activities. Austria, Denmark, United States, and Italy were among the first countries to form national biotechnology coordinating committees.[15] Germany developed the first organized government strategy for biotechnology R&D. Its institutional arrangement comprised of a variety of leading science bodies such as the Max Planck institutes and Frauenhofer institutes. The institutions have dedicated biotechnology research programmes, and some have accumulated considerable technological capabilities in the area. They are major sources of scientific knowledge in various aspects of biotechnology.

For 22 OECD Member countries which account for more than 90 per cent of all developed country agricultural R&D, total public agricultural R&D expenditures increased from about US$ 4.3 billion to about US$ 7.1 billion between 1971 and 1993. In contrast, between 1981 and

[13] The Consultative Group for International Agricultural Research

[14] See van Wijk (2000), p 5.

1993, private sector agricultural R&D increased from $4 billion to over $7 billion, at an annual growth rate of 5.1 per cent. Privately performed agricultural R&D now accounts for almost half all OECD countries' agricultural R&D.

The private and public agricultural biotechnology R&D is generating tangible products and processes. At least 70 genetically modified (transgenic) varieties of crops were registered for commercial cultivation worldwide in 1999. These include new varieties of cotton, potato, tobacco, tomato and clove. More than 15,000 field trials have been undertaken globally. New genetic modifications of more than 100 plant species are growing in laboratories, greenhouses, or in the field, providing farmers with new agronomic traits, particularly herbicide tolerance and pest resistance. In 2000 the global area under genetically improved crops was 44 million hectares mainly of maize, soya bean, cotton, canola (rappelled) and potatoes.[16] By 2001 the total global area of genetically modified crops was 52.6 million hectares. More than 30 million hectares were devoted to soybean, 10 million to maize, 7 million to cotton and 3 million to canola.[17] Seventy four percent of this area is in North America (USA and Canada) and the remaining twenty six percent in developing countries notably Argentina, China, Mexico and South Africa.

Globally, attention is largely devoted to herbicide tolerance in soybean, cotton and maize. Hericide tolerant GM crops occupied 77 percent of the total acreage. On the whole, current genetic engineering efforts have focused on a narrow range of crops and traits. There is less focus on such traits as drought and virus resistance, and crops such as pulses, vegetables and fodder. A large share of innovations in genetic engineering and GM varieties is primarily been driven by private industry for developed country markets. The products developed so far have, with few exceptions, not been targeted towards the needs of poor farmers in the developing world, particularly Africa.

Table 1: Genetically Modified Crops on the Market, 1999.

Product traits	Crops
Bt crops are protected against insect damage and reduce pesticide use. Plants	corn, cotton,

15 OECD, 1998.

16 UNDP, 2001. *Making New Technologies Work for Human Development*, p. 35. United Nations Development Programme, New York.

17 James, C. 2001. *Global Review of Commercialized Transgenic Crops: 2001*. International Service for the Acquisition of Agri-Biotech Applications (ISAAA).

produce a protein--toxic only to certain insects--found in a common soil bacterium called *Bacillus thuringiensis*, or Bt.	potatoes Future: sunflower, soybean, canola, wheat, tomatoes
Herbicide tolerant crops allow farmers to apply a specific herbicide to control weeds without harm to the crop. Gives farmers greater flexibility in pest management and promotes conservation tillage.	soybean, cotton, corn, canola, rice Future: wheat, sugar beet
Disease-resistant crops are armed against destructive viral plant diseases with the plant equivalent of a "vaccine".	sweet potato, casava, rice, corn, squash, papaya Future: tomatoes, banana
High-performance cooking oils maintain texture at high temperatures, reduce the need for processing and create healthier food products. The oils are either high oleic or low linoleic. In future, high stearate	sunflower, peanuts and soybeans
Healthier cooking oils have reduced saturated fat.	soybean
Delayed ripening fruits and vegetables have superior flavor, color and texture, are firmer for shipping and stay fresh longer.	tomatoes Future: raspberries, strawberries, cherries, tomatoes, bananas, pineapples

Increased-solids tomatoes have superior taste and texture for processed tomato pastes and sauces.	tomatoes
rBST is a recombinant form of a natural hormone, bovine somatotropin, which causes cows to produce milk. rBST increases milk production by as much as 10-15 percent. It is used to treat over 30 percent of U.S. cows.	rBST (milk production)
Food enzymes, including a purer, more stable form of chymosin used to curdle milk in cheese production. It's used to make 60 percent of hard cheeses. Replaces chymosin of rennet from slaughtered calves stomachs.	chymosin (in cheese) --the *first* biotechnology product in food
Nutritionally enhanced foods will offer increased levels of nutrients, vitamins and other healthful phytochemicals. Benefits range from helping developing nations meet basic dietary requirements, to boosting disease-fighting and health-promoting foods.	Future: protein enhanced sweet potatoes and rice; high vitamin A canola oil; increased antioxidant fruits and vegetables.

Source: http://www.bio.org/food&ag/transgenicprod.html

Regulatory Approaches

The development and commercialization of modern agricultural biotechnology, particularly its genetically modified products, have elicited a lot of controversy and emotions about its benefits and risks to human health and the natural environment. There are also ethical issues being raised about the nature and impacts of some of the techniques.

One of the major concerns about the development and use of genetically modified crops is the uncertain impact on the natural environment. Those opposed to the technology's development are concerned that novel genes might be unintentionally transferred by pollination to other plants, including weeds and also wild relatives of the crop species. There are fears that such transfers could lead to the development of resistant 'super-weeds', loss of genetic diversity within crop species, and possibly even the destabilisation of entire ecosystems. Environmentalists argue that *Bt* toxin might be taken up by non-targeted organisms, which might destroy populations of benign insect species.

Concerns have also been expressed about the risks to human health of food products derived from genetically modified crops. This is particularly the case where novel genes have been transferred to crops from organisms that are not normally used in food or animal feed products. Those opposed to genetic engineering have suggested that this might lead to the introduction of previously unknown allergens into the food chain. Controversy was sparked when a gene from a Brazil nut was successfully transferred into a variety of soya, which was being developed for animal feed. It was confirmed that the allergenic properties of the Brazil nut were expressed in the soya. However, the counter-argument was that this case demonstrated the effectiveness of scientific testing for safety. The allergen was specifically tested for during the development process, and as a result of the positive results the product was never developed for commercial use. Scientists further argue that the structure and characteristics of known allergens are well documented, and that testing for possible new allergens is therefore relatively easy.

Proponents of biotechnology argue that genetically modified products have now been on the market for several years, without a single reported case of adverse effects on human health. Potential environmental impacts will be particularly difficult to predict, monitor and manage. As scientists readily admit, no technology is ever 100 percent safe. Potential risks must be weighed against benefits. Such risk-benefit analyses should conducted be at national, ecosystem and individual socio-economic setting by government regulatory agencies, farmers and industry.

Impacts of modern agricultural biotechnology are now increasingly being seen in the context of globalization and of privatization. Concerns have been raised about the hegemony of private industry and particularly its strategy to concentrate on pesticide resistance. Private industry looks at the development and commercialization of genetically modified crops as opportunities for corporate profit. There are concerns that biotechnology firms are unlikely to address needs of farmers in developing countries unless they are commercially profitable.

Clearly, modern agricultural biotechnology offers new avenues for increasing food production in developing countries. Its potential risks must however be assessed and effectively managed. It is a set of new tools to develop drought resistant crop varieties, improvement the nutritional quality of such crops as sorghum, cassava, millet and sweet-potato, reduce post-harvest crop loses, improve livestock's resistance to disease, and enable farmers to cultivate in saline conditions. Recent assessments (see for example Quaim 1999), pathogen-free banana plants in Kenya attempt to assess socio-economic benefits of biotechnology in general and genetic engineering in particular. Quaim's *ex ante* analysis of the impact of pathogen-free banana shows for the larger farms, an average yield increase of 93 per cent can be anticipated, and this may increase to 150 per cent for smallholders.

'Golden' rice is another example of how the technology can be used wisely to contribute to the solution of food insecurity. In this case, genetic engineering has been deployed to develop a variety of rice with ability to produce beta carotene which is metabolized into Vitamin A. This new variety has the potential to address the growing problem of Vitamin A that causes partial or total blindness in several million children each year on the African continent. The challenge now is to make this variety available to African rice farmers, and possibly to develop it further for many developing country conditions.

Many of the discussions of the merits or demerits of modern agricultural biotechnology for potentially meeting the needs of poor farmers in developing countries fail to disaggregate the range of techniques and technologies that are under the rubric of biotechnology. In many cases discussions and debate often reduce the technology to a few of its products. The debate is dominated by strong Western perceptions "about the risks and benefits of this technology and how developing countries should solve their agricultural problems. Very often, stakeholders in public debates in Western countries simply NGO leaders or academic professors from developing countries who fit their view or interests and invite them to speak for the developing countries as a whole. But, apart from the fact that these experts cannot represent the view of their own country, … There is not just a single developing country perspective but several, each reflecting the particular social, political, economic and cultural circumstances."[18]

In the United Kingdom (UK) the debate may have been aggravated by the bovine spongiform encephalopathy (BSE) and traces of *Escherichia coli* found in meat products. The BSE crisis undermined public confidence in UK's institutions responsible for regulating safety of foods. In Europe there is growing public hostility to GMO products. "[G]enetically modified foods challenge traditional European ideas about food. Europeans simply regard biotechnology with suspicion, at least where their food is concerned. …All the talk of Frankenfoods in the United

[18] See Aerni, P. 2001. *Public Attitudes Towards Agricultural Biotechnology in Developing Countries: A Comparison between Mexico and the Philippines,* p. 10. Science, Technology and Innovation Discussion Paper No. 10. Cambridge, MA, USA: Centre for International Development.

Kingdom has left its mark. Because of the public's response, the European approval procedures for GMOs are stringent and thorough. …European resistance to the introduction of GMOs is so strong that approval has practically come to a stop. Europe is faced with a crisis—voters do not want GMOs and do not believe in assurances of their safety. As a result, Europe is in danger of rejecting this new science of biotechnology despite its enormous potential for good."[19] The European anti-biotechnology may influence some of the developing countries' policies. It is likely to have irreversible consequences for the entire field of biotechnology and its potential benefits for the poor in developing countries.

Governments around the world are instituting a variety of policies and laws on biotechnology. Some governments have taken a permissive regulatory approach while others a more cautious view of the technology.[20] However many developing country governments lack coherent policies and have not yet developed and implemented adequate regulatory instruments and infrastructures. As a result, in most countries, there is no consensus on how handle biotechnology and genetically modified food.

There are marked differences in developed countries' regulatory approaches. In 1986 the US adopted the "Coordinated Framework for the Regulation of Products of Biotechnology" that created a strong federal commitment to the safe development of the products of biotechnology from the laboratory, through field-testing and development, and to commercialization. This framework is founded on the principle of substantial equivalence—that any risks from biotechnology products are the same in kind to those of similar products. USA regulatory agencies are the Environmental Protection Agency (EPA), the Food and Drug Administration (FDA) of the U.S. Department of Health and Human Services, and the Animal and Plant Health Inspection Service (APHIS) of the U.S. Department of Agriculture. APHIS regulates the development and field-testing of GMO plants and microorganisms. It reviews environmental and agricultural safety of the GMOs. The FDA is responsible for assessing food safety and nutritional aspects of new plant varieties. It requires that GMO foods meet the same standards as is required of all other foods. EPA handles safety of pesticides and establishes tolerance standards or levels for substances used as pesticides in food and feed. It is also responsible for issuing permits for field testing of GMO plants with pesticidal traits.

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19 Richardson, J. 2000. 'EU Agricultural Policies and Implications for Agrobiotechnology', p. 81 in *AgBioForum*, Volume 3, Number 2&3, 2000.

20 Paarlberg, R. 2000. *Governing the GM Crop Revolution: Policy Choices for Developing Countries*. International Food Policy Research Institute, Washington, D.C.

The European Union's (EU's) main instrument for regulating the development, testing and commercialization of GMOs has evolved considerably since the early 1990s. The Directive 90/220/EEC on the deliberate release of genetically modified organisms requires an assessment of environmental impacts and promotes a step-by-step approach in granting approvals for release of GMOs. It requires an importer or manufacturer to submit a notification to the national component authority of a Member State where the GMO is to be first placed on the market before releasing it into the environment. The notification must contain information on product, and dossier of all risk assessment conducted on the product. EU's risk assessment approach takes into account how the product was developed, including the processes of generating a GMO product. Austria, France and Germany have invoked Article 16 (safety clause) of the Directive 90/220/EEC to temporarily ban the commercialization of GMO corn and oilseed in their economies.

The USA and EU regulatory approaches differ in at least two ways. First, while the USA focuses on regulating the end product, the EU tends to regulate the whole process of biotechnology R&D and commercialization of products. Secondly, "US policies tend to be more supply-driven, while EU policies are demand-driven, dominated by consumer concerns. Thus, efficiency of production is the presiding goal in the US, … In the EU, on the other hand, …emphasis (is) on quality aspects, both of products and of production methods."[21]

The transatlantic differences in handling modern biotechnology and the controversy on genetically modified organisms are starting to influence international agricultural trade patterns. "In 1996 Argentine soybean production was 11.2 million metric tons (t), of which 0.75 t were exported. The advert of transgenic soybeans helped boost production to 19.5 million tons and exports to 3.2 million in 1997, making Argentina the third largest exporter of soybeans in the world; exports increased further to 5.8 million t in 2000. In contrast, in 1997 the United States exported 1.6 million t of corn to Western Europe; in 2000 the United States exported less than 0.1 t to Western Europe because of restrictions against the importation of transgenic crops."[22]

It has been argued that restrictive regulatory regimes of European countries will undermine the growth of their knowledge base, decline of their agricultural growth and trade, but will provide developing countries with more opportunity for knowledge accumulation and expanded

21 Haniotis, T. 2000. 'Regulating Agri-Food Production in the US and the EU', p. 84 in *AgBioForum* Volume 3, Number 2&3, 2000.

agricultural trade.[23] Oehmke and co-authors argue that "developing countries have an opportunity to increase agricultural productivity and agriculture's contribution to economic growth by acquiring (importing) agricultural biotechnologies from the North. However, this requires developing and adopting appropriate biosafety and food safety regulations, and intellectual property protection (IPP), each of which is increasingly governed by international law."[24]

3. STATUS OF AGRICULTURAL BIOTECHNOLOGY IN SUB-SAHARAN AFRICA

3.1 National Research and Development (R&D) Initiatives: Some Examples

African countries can be grouped into four categories in terms of their investment and engagement in biotechnology R&D. The first group of countries is that involved in more sophisticated biotechnology activities—those pertaining to the development and commercialization of genetically modified organisms. This group consists of Egypt and South Africa. The second group is those countries engaged in the research and development of genetically modified organisms, and with some products at field-testing stage. It includes Kenya, Zimbabwe and Nigeria. The third group is those countries largely involved in tissue and cell culture applications. This includes Uganda, Tanzania and Ghana. The last group is of those countries that are not engaged in biotechnology. This group includes Ethiopia, Rwanda and many of the region's countries.

South Africa and Egypt are biotechnology leaders in the region. With considerable scientific infrastructure, the two countries have growing investment in biotechnology and are commercializing some of their products. South Africa's biotechnology R&D focus on genetic engineering of cereals: maize, wheat, barley, sorghum, millet, soybean, lupins, sunflowers, sugarcane; vegetables and ornamentals, as well as on molecular marker applications of: diagnostic for pathogen detection; cultivar identification– potatoes, sweet potato, ornamentals,

22 Oehmke, J., Maredia, M. and Weatherspoon, D. 2001. 'The Effects of Biotechnology Policy on Trade and Growth'. *The Estey Centre Journal of International Law and Trade Policy*, Volume 2 Number 2, 2002/p. 284.

23 Oehmke, J., Maredia, M. and Weatherspoon, D. 2001. 'The Effects of Biotechnology Policy on Trade and Growth'. *The Estey Centre Journal of International Law and Trade Policy*, Volume 2 Number 2, 2002.

24 Oehmke, J., Maredia, M. and Weatherspoon, D. 2001. 'The Effects of Biotechnology Policy on Trade and Growth'. *The Estey Centre Journal of International Law and Trade Policy*, Volume 2 Number 2, 2002/p. 289.

cereals, cassava; seed-lot purity testing–cereals; marker assisted selection in maize, tomato, and markers for disease resistance in wheat. The first field trials for genetically modified crops were initiated in 1990, while conditional commercial release permits were granted in 1997. The country has now commercialized insect-resistant maize and insect-resistant cotton. Other genetically modified crops expected to reach the market within the next couple of years include soya, wheat, barley and sunflower seed. By end of 2000, 41 GMO field trials had been conducted in South Africa.

Egypt has invested considerably in genetic engineering of potatoes, cotton, maize and tomatoes. The country has at least 3000 scientists active in biotechnology-related fields and more than US$ 100 million annually allocated to biotechnology R&D projects. It is focused on genetic engineering for crop improvement. The Agricultural Genetic Engineering Research Institute (AGERI) has conducted genetic transformation of potato, tomato, cucurbits, maize and cotton. With funding from the United States Agency for International Development (USAID) it undertook genome mapping of tomato and rapeseed. The Centre for Genetic Engineering and Tissue Culture at Menoufiya University has transferred *Bacillus thuringensis* (Bt) toxin genes into cotton. Similar R&D are being conducted by Cairo University's Centre for Genetic Engineering at the Faculty of Agriculture where Bt genes have been inserted into Egyptian clover.

Between 1994 and 1998 trials of GMO maize, cotton, potatoes, tomato and squash were conducted under greenhouse containment at the AGERI. During the same period field trials of GMO squash resistant to Zucchini Yellow Mosaic Virus (ZYMV), GMO potato resistant to potato tuber moth virus and GMO tomato resistant to tomato yellow leaf curl virus were conducted by the AGERI. Recently the Government of Egypt and Monsanto entered into agreement to field test and to subsequently commercialize cotton with Bollard Bt gene. The country has also imported genetically modified pharmaceutical products. These products include Actrapid 40 U HM/ml (human insulin) produced by Novo Nordisk, Roferon-A (Interferon alfa-21) produced by La Roche and Pronivel 2000 LU (Recombinant human erythropoietin) by Laboratorio Elea Argentina.

Kenya's biotechnology R&D efforts have concentrated on the application of tissue culture to improve the production of food crops. For example, the Kenya Agricultural Research Institute (KARI) is collaborating with the Institute for Tropical and Sub-Tropical Crops (ITSC) based in South Africa to micro-propagate or develop pathogen-free banana planting material. This involves rapid and sterile multiplication of banana plantlets by in vitro propagation. In 1991

KARI in partnership with Monsanto Inc. launched a project on the application of genetic engineering to develop sweet potato resistant to Feathery Mottle virus. Monsanto developed a protein responsible for virus resistance and donated it to KARI for use royalty free. There are also efforts at KARI with support of the Norvatis Foundation and CYMMIT to develop *Bt* maize.

3.2 Policies and Institutional Arrangements

Governments have a fundamental role to play in the promotion of agricultural biotechnology, its safe development and application. The role of government is crucial particularly in Africa where the national economies are weak and where the private sector's abilities to promote technological innovation are constrained by the fragmented nature of markets. This makes it crucial to institute strategic policies for mobilizing financial resources and enlarging private engagement in biotechnology R&D.

Some African countries (e.g. Egypt, South Africa and Zimbabwe) have set national goals and priorities in the area of biotechnology. However, in many other countries of the region there are no explicit agricultural biotechnology policies and defined priorities. In addition, little effort has been made to integrate biotechnology considerations into overall national development policy and planning. Implicit policy regimes such as science and technology policies make general reference to the role of biotechnology and national aspirations to engage in the development and application of the technology. In some countries (e.g. Kenya and South Africa) industrial property laws make reference to the protection of biotechnology innovations through patents.

The level of funding devoted to public biotechnology R&D in Sub-Saharan is generally low. While authoritative or reliable estimates are unavailable, in most countries of Africa government funding to biotechnology is less than US$ 1 million per year with exceptions being Egypt and South Africa. Total biotechnology funding in South Africa is over US$10 million per year, and it is estimated that half of this supports genetic modification. Over the last few years, funding of biotechnology research in academic institutions, research institutions and business has more than doubled.

Most African countries have not instituted specific policies to ensure adequate and consistent funding of biotechnology R&D. The main challenge for public biotechnology R&D in Africa is increasingly on how to find investment capital to sustain basic research and to bring laboratory findings to commercial use. Government policies to stimulate venture capital, contract research, partnerships with corporate sector and other forms of financing are much needed. Research is also need to identify specific policies on financial mechanisms for agricultural biotechnology R&D.

In addition to the above policy considerations, the development and growth of agricultural biotechnology in Africa face a number of structural constraints. First current institutional arrangements are inimical to effective biotechnology R&D. In many countries (with exception of South Africa, Egypt and Zimbabwe) biotechnology R&D are merely add-ons to other broad national research agendas. There are no specific and institutionally organized biotechnology programmes and many of the R&D initiatives are efforts of a few isolated scientists. There are no dedicated biotechnology research departments or institutions in most of Africa. In addition, most of the current biotechnology R&D are coordinated and managed in the public sector with very few and weak links with private sector. Second, in many of the countries scientific and technological infrastructure for sustained biotechnology R&D may be lacking and where it exists it is locked in isolated agricultural research bodies working on a few crops. Much of the current research in agricultural biotechnology for example is being undertaken in older established agricultural research institutions. The obvious advantage of this is that institutional memory and history can provide major benefits to the research infrastructure in the country as a whole. This however places even greater pressure on these institutions and their ability to provide adequate attention to the new technology becomes crucial. It is not clear from the above evidence that sufficient skills and funding are available for these older institutions in African countries.

3.3 Regulatory Instruments and Approaches

African countries are starting to develop regulatory systems. Their approaches vary and capabilities differ. However, many of these countries are faced with challenges of strengthening their regulatory systems to respond to domestic and international demands. In general terms, they suffer from inadequate financial and human resources and young (and in many cases absence of or existing of weak agencies) regulatory institutional arrangements.

In such countries as Zambia and Cameroon the establishment of such regimes has preceded national engagement in modern biotechnology while in South Africa, Zimbabwe, Egypt and Kenya the regimes are largely associated with efforts to develop and apply the technology. Kenya's biosafety guidelines are founded on its desire "to benefit from the development and use of modern biotechnology given that none of the existing regulations and acts are geared towards addressing specifically biosafety in the development and use of biotechnology products."[25] The proposed framework describes national biotechnology R&D efforts and states that risk assessment and management regimes should aim at promoting these efforts in such ways as to ensure that they generate products and processes that safe to the environment and human health.

Zambia's draft bill on biosafety is largely regulatory and is silent on specific measures to promote the country's engagement in modern biotechnology. It places emphasis on the creation of an institutional framework to regulate the application of modern biotechnology through inspection of R&D facilities and restriction of importation of LMOs. It contains fairly vague provisions on risk assessment. For example Part V section 14.1 states that "[u]sers shall ensure that all appropriate measures are taken to avoid adverse impacts to the environment and human health, which might arise from the use of genetically modified organisms." Section 14.2 requires users "to carry out a prior assessment of the uses as regards the risk to the environment in accordance with protocols approved by the Board". This implies that the onus of undertaking risk assessment is left to the user, possibly where the notion of user here refers to the party importing or developing the technology. Such measures may deny the country the opportunity of acquiring the necessary scientific and technological capacity to engage in risk assessment and management. Forward looking provisions would be those that require the participation of local scientists and institutions in risk assessment instead of living this scientific exercise with opportunities of technological learning to a vaguely defined entity—'user'.

South Africa's regulatory instruments are the Genetically Modified Organisms Act (GMO Act)[26] was passed in 1997, and Regulations for its implementation were adopted in 1999. According to the legislation, no person may import to or export from the Republic of South Africa, or develop, produce, use, release or distribute any GMO in the Republic of South Africa, other than under a permit for undertaking such an activity.[27] Such permit is to be issued after a technical assessment and risk analysis report have been submitted by the applicant and have been approved by the Executive Council. The GMO Regulations[28] provide that an applicant shall notify the public of any proposed release of GMOs prior to the application for a permit for such release. Public notifications shall be in the form of a standard notice published in the

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[25] National Council for Science and Technology (NCST), 1998. Biosafety Framework for Kenya. Prepared under the UNEP/GEF Pilot Biosafety Enabling Activity Project.

[26] Act 15 of 1997

[27] Section 14(2)(1), which is subject to the provisions of sub-section (2)

[28] Section 6(1)

printed media informing the public of the intended release.[29] The South African Committee For Genetic Experimentation (SAGENE), a scientific advisory committee, has been monitoring and advising on GMO development and release.

Section 2 of the GMO Act defines scope for its application. It provides that the "Act shall apply to the genetic modifications of organisms; the development, production, release, use and application of genetically modified organisms (including virus and bacteriophages); and the use of gene therapy." Excluded from the scope of application are techniques involving human gene therapy, techniques in which rDNA molecules or genetically modified organisms are not employed.

Under section 5(a) any applicant requiring to develop, produce, use or apply genetically modified organisms "or to release such organisms into the environment, to submit to the Council through the registrar, an assessment of the risk and, where required, an assessment of the impact on the environment of such development, production, use, application or release …" Section 5(k) gives authority to the Executive Council of Genetically Modified Organisms to "promote co-operation between the Republic and any other country with regard to research, development and technology transfer in the field of the genetic modification of organisms." This provision is largely a reflection of the country's aspiration to continue to invest in modern biotechnology with emphasis on the development of and trade in genetically modified organisms.

South Africa's biosafety law contains other provisions covering such areas as determination of risks and liability (section 17 para 2) and confidentiality and disclosure of information on risks and nature of genetically modified organism(s) (section 18). The law as whole should be carefully reviewed to establish the extent to which its provisions are in conformity with the Cartagena Protocol on Biosafety to the Convention on Biological Diversity.

In 1995 Egypt instituted biosafety regulations. Two decrees—Ministerial Decree No. 85 of January 25, 1995 and Ministerial Decree No. 136 of February 7, 1995—establish both procedures and institutional arrangements for regulating the development and application of modern biotechnology and its products, and more specifically for approving field testing of GMOs. Procedures for commercializing GMO crops were instituted in 1998 by Ministerial Decree No. 1648. Between 1996 and 2000 34 GMO field trials were conducted in the country.

In 1998 Kenya adopted regulations and guidelines for biosafety. These—the *Regulations and Guidelines for Biosafety in Biotechnology for Kenya*[30] explicitly recognize the role that

[29] Section 6(2)

biotechnology can play in the economic transformation of the country. They lay down procedures for field and contained testing of genetically modified organisms. A National Biosafety Committee (NBC) administered by the National Council for Science and Technology was established to implement the regulations and guidelines. It is the authority responsible for granting approvals for GMO testing, important and export. The Committee has approved field-testing of the Bt maize and the GMO sweet potato.

In 2000 Zimbabwe enacted biosafety regulations. The Research (Biosafety) Regulations—Statutory Instrument 20 of 2000—regulate the development and application of modern biotechnology in general, and genetically modified organisms in particular. Section 3 of the law defines the scope of application. It stipulates that the "regulations shall apply to …(i) techniques in which recombinant DNA molecules or genetically modified organisms are employed in *in vitro* fertilization in human beings and animals; or conjunction, …transformation or any other natural process; or polyploid induction; (ii) techniques in which genetically modified organisms as recipient or parental organisms are employed in mutagenesis; or the construction and use of somatic hybridoma cells; or …any activities involving genetically modified organisms that are declared by the Council in terms of …to constitute potentially harmful research or undertakings."

Zimbabwe's biosafety law places a lot of emphasis on institutional or agency aspects. The law, as we shall show below, creates institutional arrangements for managing biosafety at national and individual agency levels. Its coverage of such issues as risk assessment procedures, application of the precautionary principle, liability and redress, convergence with national and international trade laws, and information exchange is fairly general. The law requires the National Biosafety Board (established by section 4) to formulate detailed biosafety guidelines and standards as well as a long-term policy for safety in biotechnology. It is largely a technology management instrument and places emphasis on the promotion of biotechnology R&D.

Cameroon has also invested in the development of national biosafety legislation. With financial support from the Global Environment Facility (GEF) through UNEP the country has by January 1999 a draft bill on safety in biotechnology. The draft bill, prepared under the leadership of the Ministry of the Environment and Forestry, has three objectives to:

30 Republic of Kenya 1998. *Regulations and Guidelines for Biosafety in Biotechnology for Kenya*. National Council for Science and Technology (NCST), Nairobi.

"(i) provide a framework and guidelines for the safe, ethical and responsible research and development in modern biotechnology;

(ii) provide a framework for assessing, managing or controlling the risks associated with the use, release and transboundary movement of living modified organisms or organisms with novel traits resulting from modern biotechnology which are likely to have an adverse environmental impact that could affect the conservation and sustainable use of biological diversity, taking into account the risks to human and animal health, their socio-economic impacts, while maximizing the advantages of the technology; and

(iii) create a National Biosafety Authority charged with the overall supervision of the implementation of this law and regulations in collaboration with existing competent administrations."

Mauritius' biosafety framework focuses on measures for the safe development and introduction of genetically modified organisms. The country has already applied modern biotechnology to generate a herbicide resistant traits in sugarcane. The framework articulates the country's aspiration to extend the application of the technology to other sectors as aquaculture and recommends practices and procedures for the safe use of modern biotechnology.

OPTIONS FOR SUB-SAHARAN AFRICA

How then should African countries respond to the opportunities and challenges posed by agricultural biotechnology and in particular genetic engineering? We suggest that these countries should establish broad-based platforms to mobilize the public and scientific communities to build confidence in the technological advances associated with genetic engineering. In addition, they will need to identify their specific national priorities in food production and harness the growing body of science and innovations in genetic engineering to address specific problems. Public R&D agencies and policies dedicated to genetic engineering as well as partnerships with private industry will be crucial, and lastly African countries will need develop and implement regulatory measures to manage any environmental, economic, health and social risks associated with genetic engineering. Below we explode on each of the actions.

1. Build Public Confidence and Participation

Public perception of and confidence in modern agricultural biotechnology is one of the factors that will largely influence the extent to which countries of Sub-Saharan Africa invest in and benefit from genetic engineering to increase food production. Perceptions of the risks and benefits of the technology will influence the direction of innovation in, including commercialization of, the technology in the region. Values and psychological factors as well as confidence in scientific agencies responsible for risk assessment and management influence public perception of agricultural biotechnology. The public is also influenced by information from industry, governments, scientists, public interest groups, and media. Regulatory and scientific agencies are expected to conduct objective risk assessment and to provide the public with factual information on the nature of risks and benefits of a particular biotechnology product or process.

Science in general and genetic engineering in particular are not evolving in a socio-political vacuum. The African public and politicians have (or should have) a direct interest in scientific advances and technological developments associated with genetic engineering, yet they are not participating in the debate. In many countries of the region there are obstacles to citizens' participation in the debate on the impacts of GM crops and the potential role of genetic engineering in solving food insecurity. Considerable institutional space in the debate has been taken by isolated groups of non-governmental organizations opposed to GM crops and purporting to speak for the African rural poor, and groups of scientists who espouse the benefits of the new technology for the poor. It is unlikely that the two groups—anti and pro GM crops groups have the attention of millions of farmers in Africa. The general public and farmers in particular are not informed about the nature of the technology, its potential benefits and risks, and rarely do they participate in deciding on what crops or problems biotechnology research and development should focus on.

> One of the great challenges facing society in the 21st century will be a renewal and broadening of scientific education at all age levels that keeps pace with the times. Nowhere is it more important for knowledge to confront fear born of ignorance than in the production of food, still the basic human activity. In particular, we need to close the biological science knowledge gap in the affluent societies now thoroughly urban and removed from any tangible relationship to land. The needless confrontation of consumers against the use of transgenic crop technology in Europe and elsewhere

might have been avoided had more people received a better education about genetic diversity and variation.[31]

With the intensifying debate on GM crops, confusing counter claims from pro- and anti-GM activists, and often passive reactions by African governments, the public is likely to lose confidence in the scientific enterprise and overall decision-making authorities. What are required in the region today are processes that will legitimately bring the voices of the public to inform and change the focus and content of the current debate. Three actions that should be taken to build public participation and confidence are:

(a) Well-structured and objective assessment of African public perceptions of and/or opinions on genetic engineering and GM products should be undertaken. Such assessments must be accompanied by organized activities to provide the public with reliable and adequate information on the nature of the technology and its products.

(b) Have public stakeholders—the youth, women, farmers and other social groups—legitimately represented on bodies that are charged with regulating GM import, development and commercialization. Currently, it is difficult to determine the legitimate loci of GM decision-making in many countries of Sub-Saharan Africa. Even where biosafety frameworks have been developed and adopted (e.g. in Zimbabwe and Kenya), political institutions have either ignored these and have often made policy pronouncements that are not necessarily founded on science and informed by public opinion. What is required is the review and determination of appropriate decision-making mechanisms. Such mechanisms should have representation from all stakeholders including farmers, consumers, environmentalists and religious bodies.

If genetic engineering is to improve food production in Africa it is should be guided to co-evolve with local social and economic production systems. Appropriate social and economic institutions will be required to articulate demand for the technology and to act as 'watchdogs' for its responsible application. It is in this regard that we are proposing the establishment of broad-based platforms that enlarge public confidence in genetic engineering through open participation in priority setting and decision-making.

[31] Borlaug, N. 2000. 'Ending World Hunger: The Promise of Biotechnology and the Threat of Antiscience Zealotry' in *Plant Physiology*, October 2000., Volume 124, p. 490. www.plantphysiol.org

2. Build and Utilize Public R&D Capacity

To harness and benefit from advances in genetic engineering as well as to manage any risks African countries need to build a diverse range of human and institutional capacities. They require expertise in such areas as molecular biology, biochemical engineering, plant breeding and bioinformatics. They also need national agencies or institutes dedicated to the conduct and management of genetic engineering. Currently many African countries do not have such agencies. Their limited investments in genetic engineering and biotechnology tend to be in the form of projects scattered across the institutional landscape. This is in sharp contrast to the organization of biotechnology and genetic engineering activities in such countries as Cuba, China, India and the USA where special centers devoted to genetic engineering have been established. It is probably only in Egypt, Nigeria and South Africa where agencies dedicated to biotechnology are found.

It is crucial that each African country identifies and implement measures to build dedicated biotechnology agencies. Such efforts may focus on identifying a few national institutes with potential, and providing political support and financial resources to such institutes to grow into national centers of excellence in genetic engineering for food production. National centers of excellence should focus on specific priority problems identified through public participation. They need significant and predictable funding and should have explicit links to private sector. In addition to research, they should devote their attention to training of scientists in such new science fields as genomics.

The establishment of national centers of excellence in genetic engineering needs to go hand in hand with the creation of appropriate mechanisms to finance R&D. Current funding of biotechnology R&D is still relatively low to enable African countries to effectively engage in genetic engineering. For example, an assessment by Falconi in 1999 showed that Indonesia's total expenditure for the 1985-96 was US$ 18.7 million while Kenya spent just about $3.0 million. Nigeria and South Africa are increasing their financial investment in biotechnology and genetic engineering. Nigeria's Federal Government now provides the National Biotechnology Development Agency with an average of US$ 263 million per year for the next three years as a start-up grant. South Africa's new biotechnology strategy commits more than US$ 300 million per year from government to finance a variety of biotechnology initiatives. Other countries of the region need to invest more in genetic engineering. Some of the may wish to create special funding mechanisms (possibly National Biotechnology Funds (NBFs) for R&D. Such mechanisms would mobilize domestic and international public and private finance to support specific priority research and innovation activities that target the improvement of food production.

3. Establish and Apply Regulatory Instruments

Many African countries lack coherent regulatory instruments and institutions for risk management in relation to genetic engineering. Where instruments have been formulated and adopted by governments, there are weak institutional arrangements for enforcement of regulatory procedures. As a result, there is no consensus on how best to respond to global developments in genetic engineering and, particularly, whether to allow the importation and/or development of GM crops. The current controversy over GM food aid to Zambia clearly demonstrates the importance of governments instituting and applying regulatory instruments as well as risk assessment and management procedures.

Risk management and making decisions on the development, importation and use of GM crops are knowledge intensive responsibilities that the participation of scientists and consumers. Appropriate regulatory instruments should guide these processes. Such instruments should enable countries to invoke the precautionary principle without denying them with opportunities to address short-term and urgent needs, particularly in terms of access to and provision of food to the hungry. They should create institutional arrangements that mobilize domestic and international science to make informed decisions.

There is need to build national capacity to assess and respond to risks as well as to tap benefits generated by genetic engineering. Such initiatives as the capacity building programme of the International Center for Genetic Engineering and Biotechnology (ICGEB) will play a major role in building the capacity of African countries to conduct risk assessment. The ICGEB is engaged in the building of national capacity in industrial, agricultural, pharmaceutical, animal and human health biotechnology. The ICGEB has now more than 30 affiliated centers around the world some of which have emerged into centers of excellence in genetic engineering.

4. Build Public-Private R&D Partnerships

A large and growing portion of the scientific information and investments in genetic engineering are held by private sector mainly in the industrialized world. According to Ernst & Young, for example, in 1997 US companies invested $9.4 billion in R&D, employed 140,000 people and posted total revenues of $18 billion. At the same time there were 1,036 European companies working in the life sciences, employing more than 39,000 people directly, with revenues of $3.1 billion and $2.2 billion invested in R&D.[32] For public research institutions in Africa to access this information they will need to create strategic links with or to the private companies in the industrialized countries. The second reason has to do with the fact that commercialization of biotechnology is effectively achieved with the participation of private sector. The economic history of public R&D in many parts of the world demonstrates that public agencies have limited capacity to engage in the commercialization of new innovations. They often require private entrepreneurs to take their innovations into the economic domain.

Another good reason is that private biotechnology companies are potential new sources of financial resources for biotechnology R&D in Africa. The historical evolution of biotechnology in such countries as the United States, Germany and Japan vividly demonstrates the role of companies as sources of finance for biotechnology R&D. In Japan biotechnology companies have financed biotechnology R&D through such arrangements as venture capital. In the USA they have provided finances to university departments and scientists to undertake specific research on contract basis. Countries of Africa may wish to explore and exploit financial opportunities associated with partnering with private companies.

CONCLUSION

Rapid advances scientific and technological advances associated with modern agricultural biotechnology offer both challenges and opportunities to African countries to address some of the causes of persistent food insecurity. Tapping the opportunities and confronting the challenges will require knowledge-based platforms for decision-making and increased investment in scientific development. Countries of Africa should eschew the either or, pro and anti- sentiments and erect scientific and technological foundations for harnessing benefits of the new science while at the same time reducing risks. It is through their own investment in genetic engineering that they are able to make informed decisions on which specific genetically modified crops to import or accept as part of any food aid. Furthermore, with increased investment in genetic

[32] See Falconi, C. 1999 for Ernest and Young data.

engineering that targets specific food production challenges, the region may be in possible to build the basis for food security: reducing dependency on food aid. Africa requires genetic engineering as part and parcel of its endogenous scientific and technological development.

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