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Review

Challenges and impacts of agricultural biotechnology on developing societies

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The most critical areas in the world for bringing economic prosperity and stability are the developing countries. Agricultural productivity in these countries must advance more rapidly to meet growing food demands and raise incomes while protecting the environment for future generations. Agricultural biotechnology has the potential to play a large role toward this achievement. Sadly, this opportunity remains a mirage for most developing societies because of numerous challenges that prevent them from benefiting from the technology. This review identified these challenges to include lack of effective leadership, poor funding of agricultural biotechnology research and development, lack of research focus and infrastructure, and inadequate human resources and expertise. It further appraised the benefits and risks of agricultural biotechnology to developing societies. Among the potential benefits of the technology are: an increase in the productivity of tropical commodities to meet future food needs, new opportunities for the use of marginal lands, and a reduction in the use of agrochemicals. However, associated with the technology are diverse questions of safety, ethics, and welfare. The review concluded with recommendations on the appropriate use and application of agricultural biotechnology in developing societies. They include adequate regulatory measures, public debate, human resource development and training, public-private sector collaboration, intellectual property management, and support from international development organizations.

Key words: Agricultural biotechnology, challenges, impacts, developing societies.

INTRODUCTION

The problem of food insecurity, poverty, disease, and hunger in many nations, especially the developing ones, has triggered off a lot of research efforts to forestall these menaces. Reports show that about 1.2 billion people worldwide live in poverty (earn less than $1 a day) and majority (70%) of them live in rural areas (Zakiri, 2002). Ozor and Igbokwe (2007) observed that the outlook for developing societies in food and fibre production is particularly grim. According to Oladele and Akinsorotan (2007), there are about 790 million undernourished people in developing countries whose food intake is insufficient to meet basic energy requirements on a continuous basis. The ecologically acceptable expansion of arable land is no longer possible to support the ever growing population of people in developing societies- a society with a relatively low standard of living, undeveloped industrial base, and moderate to low Human Development Index (HDI). Unfortunately still, their production systems and practices are not efficient to meet with demands. Growth rates in yields have been decreasing in most parts of developing societies and this declining trend is expected to continue if nothing urgent is done (Ozor and Igbokwe, 2007). Mugabe (2003) reported that in order to meet the increasing demand for food and enlarge the prospects for food security in developing societies, increases in agricultural productivity through improvements in crop and livestock yields will be required. New scientific and technological advances therefore, remain the most probable option for sustainable food and fibre production in developing societies. This is because the problem of food insecurity in most developing societies has remained intractable using the conventional traditional methods of food production. Meanwhile, research in recombinant genetics and biotechnology develops plant and animal species that provide reliable high yields at the same or lower costs by breeding-in qualities such as better product quality, resistance to diseases, pests, and stress factors, etc (Ozor and Igbokwe, 2007).

Agricultural biotechnology research and development (R and D) represents one of such novel approaches with the capability of changing the face of agriculture so as to meet the increasing and varying needs (food, feed, fibre and fun) of people in the new millennium. This role has been acknowledged since its commercial introduction in 1996 (Penn, 2003). Modern agricultural biotechnology has the potential to play a large role in more rapidly advancing agricultural productivity in developing countries while protecting the environment for future generations. This technology represents the latest scientific progress in the new millennium aimed toward fighting the persistent food crisis situations of many developing societies. According to James (2000), transgenic crops, often referred to as genetically modified (GM) crops, represent promising technologies that can make a vital contribution to global food, feed, and fiber security. Agricultural applications cover fields as diverse as traditional fermentation technology in food processing to the use of a particle gun in transferring genes from one plant or animal species to another. However, three distinctive features occur between modern and traditional agricultural biotechnology as follows: 1.The creation of modern agricultural biotechnologies involves input from basic scientists, such as molecular and cell biologists and cytogeneticists, who are not part of the traditional agricultural research extension network.2. The processes and or products of modern agricultural biotechnology are often patentable. This has greatly stimulated private investment in agricultural research. 3. Research in modern agricultural biotechnology is expensive. Simple forms of modern agricultural biotechnology research, employing techniques such as tissue culture to propagate a disease-free crop, may cost not less than US. $1M and take 3 – 6 years (International Institute of Tropical Agriculture [IITA] and the Technical Centre for Agricultural and Rural Cooperation [CTA], 1992).

According to Glover (2001), recent scientific advances in genetics have opened up a range of potential new applications of modern biotechnology. In agriculture, these include the ability to: manipulate genetic material and transfer genes between organisms in order to promote desired traits and suppress unwanted ones, propagate disease-free planting material in the laboratory, and support traditional breeding techniques. The author further noted that the latest “big thing” in agricultural biotechnology are: genomics (mapping of complete organism genomics), and bioinformatics (computer processing of masses of genetic data).

The implications of the aforementioned features of agricultural biotechnology for developing society are clear. It shows that basic modern agricultural biotechnology research is costly and too demanding of scientific skills for the limited resources of most of the developing countries. Furthermore, data on the current global distribution of commercialized transgenic crops show how, with the exception of China and Argentina, there has been little impact in the developing societies as yet (Table 1) (James, 2005). This is as a result of numerous challenges, erroneous ideas and beliefs, which encumber research, development, and adoption of modern agricultural biotechnology in developing societies. Therefore, what are the challenges that hinder developing societies from embracing this innovation? What impacts does the new technology have on them? And how then, could agricultural biotechnology be used or applied so that majority of the developing societies benefit from the technology. These questions form the main focus of this paper.

CHALLENGES TO AGRICULTURAL BIOTECHNOLOGY IN DEVELOPING SOCIETIES

While agricultural biotechnology holds enormous promise for significantly increasing food production and relieving already strained land and water resources, it has become an emotional issue among some consumers, environmental groups and some societies. As the science continues to be developed it clearly presents numerous challenges which hinder its development throughout the food chain. These include:

Lack of effective leadership

The lack of effective leadership in science and technology and the absence of clear priorities, policies and investment strategies in Research and Development (R and D) pose great challenge to agricultural biotechnology development in developing societies. The controversy about Genetically Modified (GM) food aid in Africa for example, will continue to confuse policy makers and cause public anxiety if scientists and politicians in developing societies do not provide leadership to articulate their aspirations and interests in biotechnological development. Already, in a number of countries, there is inconsistency in political pronouncements and policies on biotechnology and its GM products. The public is often left confused about contradictory positions and polices on the role of the technology in agriculture (Mugabe, 2003). Sometimes, international political system influence political leaders’ decision to reject proposals on biotechnology development.

Poor funding of agricultural biotechnology research and development (R&D)

Biotechnology developments need high inputs of finance which are in short supply in most developing nations.

Table 1. Global distribution of commercialized transgenic crops in 2004 and 2005 by Country (Million Hectares).

S/N	Country	2004	%	2005	%	+/-	%
1	USA	47.6	59	49.8	55	+2.2	+5
2	Argentina	16.2	20	17.1	19	+0.9	+6
3	Brazil	5.0	6	9.4	10	+4.4	+88
4	Canada	5.4	6	5.8	6	+0.4	+7
5	China	3.7	5	3.3	4	-0.4	-11
6	Paraguay	1.2	2	1.8	2	+0.6	+50
7	India	0.5	1	1.3	1	+0.8	+160
8	South Africa	0.5	1	0.5	1	- -	- -
9	Uruguay	0.3	<1	0.3	<1	<0.1	- -
10	Australia	0.2	<1	0.3	<1	+0.1	- -
11	Mexico	0.1	<1	0.1	<1	<0.1	- -
12	Romania	0.1	<1	0.1	<1	<0.1	- -
13	Philippines	<0.1	<1	0.1	<1	<0.1	- -
14	Spain	<0.1	<1	0.1	<1	<0.1	- -
15	Colombia	<0.1	<1	<0.1	<1	<0.1	- -
16	Iran	- -	- -	<0.1	<1	- -	- -
17	Honduras	<0.1	<1	<0.1	<1	<0.1	- -
18	Portugal	- -	- -	<0.1	<1	- -	- -
19	Germany	<0.1	<1	<0.1	<1	- -	- -
20	France	- -	- -	<0.1	<1	<0.1	- -
21	Czech Republic	- -	- -	<0.1	<1	- -	
	Total	81.0	100	90.0	100	+9.0	+11

Source: James, 2005.

Even where the economy of such nations is somewhat stable, the budgetary allocation to science and technology and biotechnology R and D in particular is not encouraging. Much of the developing societies today depend on public sector investments in agricultural research and extension, but over the years, budgets for research and the quality of national research institutions have declined in many developing countries. For example, in Nigeria, total agricultural R and D spending showed a negative average growth rate of 2 percent per year between 1975 and 1995. Total spending dropped by 66.6% from an average of about 130 million US dollars in the mid 1970s to less than 50 million US dollars in mid 1990s (Beintema and Ayoola, 2004). Support from developed countries and donor agencies are declining and there has been a tendency to spread investments in research and extension over a large number of institutions, rather than developing a few quality ones.

Lack of research focus and infrastructure

Most developing nations have not identified specific areas of modern agricultural biotechnology in which to invest to meet specific goals. In the absence of identified national priorities, it is difficult to make informed, long-term policies. Many developing countries tend to spread their limited financial and human resources thinly across diverse agricultural biotechnology activities and research agencies (Kasonta, 1999). While many have recognized the importance of setting biotechnology priorities and consolidating resources in a few research institutions that have the potential of growing quickly in centers of excellence in biotechnology, the countries have not established and applied strategies of identifying such institutions and ways of setting priorities. They continue to operate with isolated, competing and often scientifically weak research agencies. Such agencies lack scientific and technological infrastructure for sustained agricultural biotechnology R and D (Mugabe, 2003).

A recent survey of biotechnology R and D in Nigeria by Machuka (2001) concluded that “the ability to carry out research in modern biotechnology in 17 institutions shows that at least 40% of the institutions are unsuitable to undertake research due to lack of electricity and inadequate tissue culture facilities among others. The Yitzhak Rabin laboratory for micro-propagation and biotechnology is the only one fully equipped for tissue culture work and probably ranks as the best in the country. This is a sad situation, since Nigeria has arguably the largest number of trained molecular biologists in sub-Saharan Africa".

Inadequate human resources and expertise

Agricultural biotechnology is an intensive research area which needs high capacity of human resources to achieve substantial benefits. Most developing societies lack this human capacity and where they are available, it is in short supply or they are not given enough opportunities to express themselves. This result in their drifting away to the already developed societies where their knowledge is valued – a phenomenon oddly referred to as *brain drain*. The low level of scientific literacy in developing societies does mean that most people will not be able to draw informed conclusions about important agricultural biotechnology issues. Consequently, it is conceivable that a small number of activists can argue the case against genetic engineering in such emotive and ill-reasoned ways that the public and politicians are involved. 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 agricultural biotechnology R&D should focus on. Agricultural extension has a great role to play here through mounting of awareness campaigns on biotechnology product information, disseminating proven and reliable biotechnology products, involving end-users to participate in issues relating to biotechnology R&D, and supporting end-users to adopt the new innovation in order to achieve food security.

In Nigeria, the number of full time equivalent researchers at government research institutes declined in the late 1980s and early 1990s due partly to lack of funds and the drift to universities with higher wages (Beintema and Ayoola, 2004). However, a survey by Falconi (1999) shows that the number of researchers in agricultural biotechnology doubled in Kenya between 1985 and 1996. It quadrupled in Zimbabwe, with at least a 5 times increase in Ph.D holders. Nevertheless, the level of expenditure per researcher or scientist declined in most countries.

IMPACTS OF AGRICULTURAL BIOTECHNOLOGY ON DEVELOPING SOCIETIES

There is no doubt that genetic engineering (GE) has the highest profile among the new technologies in agriculture today. Transgenic crops like maize, rice, wheat, soybean and cotton are among the top priorities for the agricultural biotechnology industries. This notwithstanding, GE also has created the strongest sense of unease and resistance among consumers, developing-country farmers, and environmentalists. While there are undoubted benefits from the use of transgenic organisms, it is important to ensure that such systems do not cause problems of safety to people and the environment or create unacceptable economic, social, moral, or ethical issues.

The likely benefits of agricultural biotechnology in developing societies are: an increase in the productivity of tropical commodities to meet future food needs, new opportunities for the use of marginal lands, and a reduction in the use of agrochemicals. Production efficiencies and bigger yields provided by agricultural biotechnology may bring down prices for rural poor and urban consumers in the long run. Also, GE is increasingly being applied to many breeding programmes to achieve the same aims as the traditional methods but offering two main advantages; the introduction of genes can be controlled with greater prediction and precision than by previous methods, and that the introduction of genes into unrelated species is not possible to achieve by traditional methods. According to Brookes and Barfoot (2006), GM technology has to date delivered several specific agronomic traits that have overcome a number of production constraints for many farmers. This has resulted in improved productivity and profitability for the 8.5 million adopting farmers (mostly in industrialized nations) who have applied the technology to over 87 million hectares in 2005.

The application of GE to food production is intended to enhance the useful and desirable characteristics of the organisms and to eliminate the undesirable ones. The overall aim of the food industry with respect to GE will be to improve the quantity and to increase the quality and properties of existing food products, to produce new products and, of course, to improve financial returns. In 2005 alone, the direct farm income benefit from biotech crops was about $5 billion. This is equivalent to having added about 3.6% to the value of global production of four main crops of soybeans, maize, canola and cotton (Brookes and Barfoot, 2006). Iran and China are the most advanced countries in the commercialization of biotech rice, which is the most important food crop in the world, grown by 250 million farmers, and the principal food of the world's 1.3 billion poorest people, mostly subsistence farmers (James, 2005). Thus, the commercialization of biotech rice has enormous implications for the alleviation of poverty, hunger, and malnutrition, not only for the rice growing and consuming countries in Asia, but for all biotech crops and their acceptance on a global basis.

Generally, consumers have always shown a willingness to pay more for better and more convenient products and to reject products that do not achieve their expectations. New agricultural biotechnology now offers a major opportunity to tailor food products to public demand. According to Smith (1996), many benefits that GE offers in agriculture include: disease and pest resistance, weed control, animal growth hormones, improved food micro-organisms, novel products, improved keeping quality, tailored products with improved qualities, etc. It is then a matter of choice for the consumer to consider between products of traditional agriculture or agricultural biotechnology based on their needs, targets, and aspirations.

Modern agricultural biotechnology can also be used to improve “orphan commodities”. These are crops which receive little international research attention and which are very important to developing country’s agriculture. Some examples of these commodities are cassava, sweet potatoes, yams and legumes such as cowpea and bean.

Conversely, while agricultural biotechnology presents enormous potential for healthcare and the production, processing and quality of foods by genetic manipulation of crops, fertilizers, pesticides, vaccines, and various animal and fish species, the implications of these new biotechnological processes go well beyond the technical benefits offered. Associated with genetic manipulation are diverse questions of safety, ethics, and welfare. The risks from any new technology are divided into those inherent to the technology and those that transcend it (Leisinger, 1996). Technology-inherent risks of agricultural biotechnology, such as undesirable mutations, must be dealt with appropriately by the biological sciences. The transcendent risks are outside of the biotechnology; they are the social, economic, and cultural factors that may distort or obstruct its benefits. The major negative impacts of agricultural biotechnology include:

Safety problems

In the 1970s when genetic engineering experiments with micro-organisms were first being developed, many molecular biologists believed that the process was unsafe and that manipulated micro-organisms should be strictly contained and prevented from release to the environment. The fundamental fear was, and with many still is, that genetically engineered micro-organisms could escape from the laboratory into the environment, with unpredictable and perhaps catastrophic consequences. It was believed that such released micro-organisms could upset the balance of nature or that foreign DNA in the new micro-organism could alter its metabolic activity in unpredictable and undesirable fashion (Pronk, 1992 and Smith, 1996). It is also feared that various technologies being in-built into the new agricultural biotechnology products will in future make seeds unviable. The undesirable spread of GM species and strains and the reduction in the genetic base of the major trade and food crops and animals increase the risks of disasters and encourage genetic erosion (Pronk, 1992). The safety issue has led to some countries or regions and corporate bodies taking steps aimed at banning or suspending the use of GM products. For example, the Brazilian state of Rio Grande de Sul has declared itself a GM-free state. A Brazilian court has barred the planting and distribution of GM soybean until environmental impact assessment is carried out. Also, the Japanese Ministry of Agriculture announced suspension of approval of Bt-crops in Japan until revised protocols are developed for GM-crops (Uguru, 2003). Similarly, China is cognizant of the need for biosafety management in order to ensure protection of the environment and consumers, and this is a consideration in the pending approval of Bt rice, which is expected in the near-term (James, 2005).

Smith (1996) observed that while the public has readily accepted medical products produced from GMOs, they are much less willing to accept such procedures with food. Genetic engineering is seen as unnatural and unnecessary in food production. The safety of the human food supply is based on the concept that there should be a reasonable certainty that no harm will result from its consumption. Foods or food ingredients derived from GMOs must be considered to be as safe as, or safer than, their traditional counterparts before they can be recommended as safe. While the original anxieties about GM products were perceived mainly on safety issues, other social, economic, moral, and ethical issues have come more to the forefront.

Substitutability effect

Agricultural biotechnology may aggravate the prosperity gap between the developed and developing nations by replacing tropical agricultural exports with genetically engineered products of the developed societies. For example, genetically produced vanilla flavoring could displace 70,000 small farmers in Madagascar; genetically improved cocoa varieties could displace thousands of small holder farmers in West Africa in favour of plantation farmers in the newly industrialized economies of Asia; genetic production of sweeteners could displace the total sugarcane exports of Cuba and Mauritius (Leisinger, 1996).

Furthermore, liquid maize sweetener has replaced about 50% of the sugar consumed in the USA and accounts for 15% of the world’s sweetener market (IITA and CTA, 1992). The high price support for domestic sugar in the USA (designed to protect the domestic sugar beet industry), provided the incentive for developing liquid maize sweetener. This resulted in a sharp drop in demand for sugarcane exports from the developing countries. Increased milk production from fewer cows by the injection of genetically engineered hormones will certainly result in many small farmers being put out of business. The failure of the General Agreement on Trade and Tariffs (GATT) negotiations to reach agreement on reducing agricultural protection in the developed countries creates an additional incentive to produce substitutes (IITA and CTA, 1992).

Widening income gap (inequality)

Agricultural biotechnology is now evoking the same objections that have been raised against Green Revolution

– that its benefits are distributed inequitably in favour of the large, rich, and privileged farmers who desire earlier and greater benefits from the introduction of powerful technologies than do the socioeconomically disadvantaged ones. The use of agricultural biotechnology can no doubt provide real incentives to agricultural development, but in socially and politically defective setting, it is much more likely to favour a small and powerful minority than to improve conditions for the poor.

There is obvious concern that the control of genetically engineered crops and animals by multinational companies, and the need of the later to recoup the high research and investment costs incurred in their development, will imply that only high technology farmers will be able to carry the cost burden. This will not be true of the farmers in the developing societies. Small/peasant farmers prevalent in developing societies cannot afford the cost of new seeds or other agricultural biotechnology products more especially when traditionally; they have relied on self-grown seeds and products. Without social reforms that enable the middle and lower strata of society to share in the gain, such as land reform and special support programmes for small farmers, technological innovations can work against the development goal of equity.

Exploitation of rich indigenous resources of developing societies

The exploitation of indigenous genetic resources without appropriate compensation to indigenous population is a cheat on the developing societies. Some people fear that multinational firms or even government research institutes could gain control of genes of plants and animals native to the developing societies free of charge and use them to produce superior patented varieties that would then be sold back to developing countries at higher prices. It is imperative to keep open access to the genetic riches of the developing world and at the same time enable the people who have helped to build and preserve this wealth through decades of indigenous selection to benefit equitably from the commercial returns on gene exports. Article 19 of the RIO convention on Biological Diversity of 1992 established that remuneration is due to developing countries for genetic material (Leisinger, 1996). Provisions should therefore be made in biotechnology R&D to conserve the indigenous genetic resources which serve as the basis for research process.

Less attention to R&D of interest to developing societies

There is concern from all sides of the biotechnology debate that crops of importance to developing nations are not being developed. The biotechnology firms who represent more than half of the total investment in biotechnology research, admit they are seeking a profit, and focus on crops, animals and technologies designed for the industrialized farmers and sophisticated markets of the developed nations. For example, herbicide tolerant soybean occupied 54.4 million hectares globally, representing 60% of the global biotech crop area of 90.0 million hectares (mostly in the industrialized nations) for all crops (maize, cotton and canola) in 2005 (James, 2005). Staple crops such as cassava, yam, plantain, millets, rice, wheat, mustard/rapeseed, cabbage, cauliflower, pigeon-pea, etc., and the production constraints of the developing societies are neglected or likely to receive too little attention without continued strong support for public sector research. The focus on GM technology distracts attention and diverts resources from technologies, which are more appropriate to developing country farming.

Ethical issues of agricultural biotechnology

A report by the Committee on the Ethics of Genetic Modification and Food Use, 1993 in United Kingdom in Smith (1996) identified some of the main ethical concerns relating to food use of certain transgenic organisms to include transfer of human genes to food animals (example, transfer into sheep of the human gene for factor IX, a protein involved in blood clothing; transfer of genes from animals whose flesh is forbidden for use as food by certain religious groups to animals that they normally eat (example, pig genes into sheep) would offend Jews and Muslims; transfer of animal genes into food plants that may be of particular concern to some vegetarians (especially vegans); and use of organisms containing human genes as animal feed (example yeast modified to produce human proteins of pharmaceutical value and the spent yeast then used as animal feed). Consequent upon these, products from transgenic organisms containing copy genes that are ethically unacceptable to some groups of the population subject to dietary restriction or their religion should be so labeled to ensure choice.

Finally, Commandeur and Roozendaal (1993) in Leisinger (1996) assessed the impact of agricultural biotechnology on different countries and concluded as follows:1. High food importers with strong technological potential could benefit the most, since the trends would push their economies toward self-sufficiency.2. High food exporters with strong technological potential could benefit by diversifying their exports.3. Net importers of food with weak technological potential could benefit in the short term from lower world prices. In the long term, domestic food production would suffer.4. Countries that are net exports of potentially substitutable products and have low technological potential are the most vulnerable. This category includes most of the developing societies like sub-Saharan Africa and the Caribbean.

RECOMMENDATIONS ON THE APPROPRIATE USE AND APPLICATION OF AGRICULTURAL BIOTECHNOLOGY IN DEVELOPING SOCIETIES

How then, could agricultural biotechnology be used or applied so that majority of the developing societies benefit from the potential benefits while being cautious of the risks inherent in the technology? We have previously suggested that these countries should establish broad-based platforms to mobilize the public and scientific communities to build confidence in the technological advances associated with GE. Individual countries need to identify their specific national priorities and preferences in food production, and harness the growing body of science and innovations in genetic engineering to address specific issues (Ozor and Igbokwe, 2007). Below are highlights of some recommendations:

Adequate regulatory measures

A major issue that will affect successful applications of biotechnology to agriculture is the regulatory climatic governing the release of new products. A safe and efficient regulatory process, able to ensure public health and environmental safety, is in itself a comparative advantage in biotechnology. Developing societies will need to develop and implement regulatory measures to manage any environmental, economic, health and social risks associated with genetic engineering (Mugabe, 2003). Government regulations will represent a critical determinant on the time and costs in bringing a product to market. Regulatory agencies and structures can act as 'gate-keepers' for the development and availability of new agricultural biotechnology products. The rules governing the trade of biotech-derived products, and indeed all products, must be based on scientific risk assessment and risk management. Regulatory and scientific agencies are expected to conduct objective risk assessment and to provide the public with factual information on the nature of the potential risks and benefits of a particular biotechnology product or process.

The World Trade Organization (WTO) Agreement on sanitary and phytosanitary measures (SPS agreement) requires that measures regulating imports be based on sufficient scientific evidence and that countries operate regulatory approval procedures without delay. For example, the Codex Alimentarius Commission has approved science-based guidelines for biotechnology food safety assessments relating to human health. These guidelines were approved unanimously by the commission, which is composed of 169 members, including the United States of America, European Union member countries, and the vast majority of developing countries (Alan, 2003).

In most developing countries, adequate regulatory framework has not been put in place as a result of low activity in modern agricultural biotechnology and its products. However, several United Nations Organizations, including Food and Agriculture Organization (FAO), United Nations Environment Programme (UNEP), United Nations Industrial Development Organization (UNIDO), and World Health Organization (WHO), are reviewing the needs of their member countries in order to advise on the development of safe products and efficient regulatory processes.

Public debate

Public debate is essential for new agricultural biotechnology products and processes to grow. Public confidence in modern agricultural biotechnology is one of the factors that will greatly influence the extent to which countries of developing societies invest in and benefit from genetic engineering to increase food production. Public understanding of these new technologies could well hasten public acceptance and confidence. Protagonists and admirers of agricultural biotechnology need to sit up and take notice of, and work with, the public. People influence decision-making by governments through the ballot box or public opinion. Ultimately, the benefits of agricultural biotechnology will speak for itself in the nearest future.

Processes that will legitimately bring the voices of the public to the fore to inform and change the focus and content of the current debate are required. According to Mugabe (2003), three actions that should be taken to build public participation and confidence are: well-structured and objective assessments of developing country's public perceptions of or opinions on, GE 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; stakeholders – youths, women, farmers, and other social groups – should be legitimately represented on bodies that are charged with regulating GM import, development and commercialization; and if genetic engineering is to improve food production in developing societies, like Africa, it should be guided to co-evolve with local, social and economic production systems.

Human resource development and training

Key elements of any national strategy to foster the development and safe application of agricultural biotechnology are the building and or mobilization as well as the efficient utilization of scientific expertise through training and establishment or acquisition of physical infrastructure (laboratories and related equipment) for R and D (Mugabe, 2003). The enhancement of capacities to engage in the analysis and making of policies on agricultural biotechnology should be treated as a priority by national and international programmes. Barriers to entry into modern agricultural biotechnology can be broken through learning-by-doing and efficient use of such traditional techniques as tissue culture (Juma et al., 1995).

Training in risk management and assessment procedures will be crucial to the building of national capacity for agricultural biotechnology R and D. Such training could be offered through international agencies such as the International Center for Genetic Engineering and Biotechnology (ICGEB) and by the biotechnology industry. Post-doctoral fellowships in advanced laboratories are a key component of keeping abreast of the latest advances worldwide. Graduate and undergraduate training underpin the development of in-country capability in the basic biological sciences. Mobilizing the basic scientific skills usually found in universities to solve agricultural problems will require new policy and institutional arrangements and more financial resources.

Public-private sector collaboration

The major change in the funding of agricultural research in industrialized countries in the past decade has been the greatly increased role of the private sector, largely in modern biotechnology (IITA and CTA, 1992). They further noted that at least half the current funding of R and D activities in agricultural biotechnology worldwide comes from the private sector. It is an emerging trend in Latin America, and in parts of Asia and the Middle East, but there is little evidence of it as yet in Africa. Public R and D agencies and policies dedicated to GE as well as partnerships with private industry are necessary.

In most developing societies, public sector investment is still the main source of finance for biotechnology R and D. For public research institutions in Africa to access scientific information and investments in genetic engineering, they will need to create strategic links with private companies in the industrialized countries. Alliances between the developing country's public biotechnology R and D agencies and leading private companies which form the pool of scientific expertise in biotechnology could help the farmer build competencies in the new technology. There is therefore a need for greater public-private sector collaboration in relation to agricultural biotechnology and its application to problems in the developing world. This will require: continued public sector investments from domestic and external resources, public-private sector partnership, innovative funding mechanisms on the part of international development agencies, and involvement of both local private sector companies and transnational companies.

Intellectual property management

One of the major issues that will affect the application of biotechnology in agriculture is the protection of intellectual property. The lack of patent protection is a major disincentive for private sector investment in biotechnology in developing societies. The advantages of the availability of intellectual property protection are that it encourages the development of local research capability and greater in-country investments in biotechnology. Admirers claim that intellectual property rights (IPRs) will encourage innovation and enable innovators to reap a just reward for their investment in R and D. Notably, only the new innovation should be patented while the existing knowledge and plant/animal material, which were used as a basis for the innovation, remain in the public domain.

However, a major disadvantage is that it involves giving proprietary protection to living organisms, which some consider to be part of the common heritage of mankind. Critics retort that IPRs, particularly patents, restrict the flow of knowledge and information and therefore inhibit R and D by others. Patents have also been granted for quite trivial inventions and developments, which fall short of the legal test for patentability (Barton, 2000 in Glover, 2001). Therefore, each country needs to weigh the benefits and costs of IPRs in agricultural biotechnology and frame its policies accordingly.

Support from international development organizations

There should be increased support by international agencies for the development of agricultural biotechnology in the developing societies. This could come in form of loans to undertake specific biotechnology research projects in agriculture, new joint ventures to help local companies participate in commercial development of agricultural biotechnology, etc. Such organizations include the World Bank, international finance corporations, rich nations, Non-Governmental Organizations (NGOs), private biotechnology companies, etc. For example, the United States of America (USA) supports the development of biotechnology-derived staple food crops in developing countries that will fight disease such as insect-resistant cowpeas, disease-resistant bananas, cassava, and sweet potatoes (Alan, 2003). The USA government also provides technical assistance to countries to help them develop their own capacity to regulate this technology and put it to use for the benefit of their citizens.

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