

APPLICATIONS OF BIOTECHNOLOGY IN FOSTERING HEALTH AND WELL-BEING: DIRECTIONS FOR HEALTH AND MEDICAL RESEARCH IN DEVELOPING COUNTRIES

Mumah, S. C. J., Muoma, J. V. O., and Mwaniki, J. W., Kenyatta University

Abstract

Biotechnology and Globalization are the two critically important forces of the 21st century, which not only carry with them immense potential benefits in medicine, but also risks. Biotechnology has a considerable potential for improving human health of the developing countries now and in the future since information generated by advances in genetics and biotechnology has major benefits for the prevention, diagnosis and management of communicable and genetic diseases. While the benefits of technological advances in biotechnology may be obvious, regulatory principles and capacities at both National and International levels are inevitable to safeguard the public health against potential risks and hazards resulting from research and its application. Such principles as the WTO and TRIPS on intellectual property rights and patenting and Cartagena protocols on biosafety become imminent. Some of the applications of biotechnology in medicine and agriculture include, among others, DNA diagnostics in the management and control of communicable diseases and identification of drug resistant organisms; control and management of genetic disorders; production of genetically modified agricultural products.

Although these applications are likely to benefit comparatively more of the poor countries today than the richer countries, most biotechnology research is carried out in the developed world and is primarily market-driven. Most of Sub-Saharan countries currently have either rudimentary, fragmentary or not yet being able to evolve biotechnology capabilities. There is however, an urgent need to initiate a process whereby developing countries can gain the kind of expertise in biotechnology, which is required for application to their own particular health needs. This paper discusses the ethical issues, potential risks intellectual property rights and applications of biotechnology in fostering health and well-being. It also points out the future direction of biotechnology and its enormous potential for improving health care in resource poor developing countries of the Sub-Saharan Africa region.

Introduction

Biotechnology and globalization are the two inextricably linked forces of the 21st century that are growing with substantive momentum (Baisley, 2002; Bruntland, 2002). Biotechnology has a considerable potential for improving human health of the developing countries in the future. The information generated by advances in genetics and biotechnology has major benefits for the prevention, diagnosis and management of communicable and genetic diseases. Furthermore, research directed at pathogen genomes provides insight on disease transmission and on virulence mechanisms, and how infective agents avoid host defenses (WHO, 2002).

While all these are direct, indirect benefits can also be gained from application of the technology in agriculture. Research into plant genomics and the genetic modification of crops has great potential for improving human health through nutritional gains and the production and delivery of vaccines and therapeutic agents (WHO, 2002). The aims of the genetically modified plant technologies are two fold: to enhance the nutritional value of the crop species and to confer resistance to pathogens. However, regulation of the safety of genetically modified foods is critically important to promote consumer health.

Currently, the major constraints limiting biotechnology research and its application in developing countries are inadequate research capacity and strength. Clearly, only the developing countries that have evolved substantial biotechnology capabilities will benefit from the promises of technological advances in promoting public health. However, some of developing countries including Kenya have either poor or nonexistent biotechnological facilities and strengths. These countries cannot rely on the developed world because, due to the largely market driven research agenda, very few researches developed in these countries are aimed for application in developing countries (WHO, 2002). Consequently, it is crucial for developing countries to establish their own research capacity in all areas of biotechnology and genomics so that the technology can be applied to address local and regional health needs.

Biotechnology initiatives require the exploration of and intensive studies in terms of research and development in order to make available, to the rest of the world, the benefits of biotechnology. These include cheaper and more efficacious drugs derived from natural resources, better therapies, and higher crop production with improved nutrients, taste and quality. This brief discussion paper outlines the application of biotechnology for improving public health, its potential risks and the ultimate future direction of biotechnology and genomics.

DNA Diagnostics for Communicable Diseases: HIV/AIDS

Work in Latin America has demonstrated that molecular technologies can be adapted to local conditions and disease priorities in developing countries and are more rapid, versatile and sensitive than alternative methods (Harris *et al.*, 1993; Harris, 1996; Harris and Tanner, 2000). Furthermore, they can be cost effective in low budget situations. Depending on disease priorities, Polymerize Chain Reaction (PCR) based techniques can be implemented to enhance public health programs. For instance, having proved to be simpler and more sensitive than existing techniques, PCR has been adopted as a routine diagnostic procedure for Leishmaniasis by the Nicaraguan Ministry of Health (Harris *et al.*, 1993). It has also improved detection of dengue in Nicaragua and Paraguay. Similarly, PCR was also used in 1995 to rule out dengue as the cause of an outbreak of hemorrhagic fever in northern Nicaragua, which led to the identification of Leptospirosis as the culprit. Certainly, PCR based techniques are going to have a very potential value in the surveillance of the circulating HIV subtypes both at country and regional levels. It is now understood that, due to the existence of the HIV virus in multiple subtypes (see *appendix 1*) with varying antigenicity, different regions of the world will probably need different types of vaccine, somewhat depending on the locally circulating viral subtypes. Consequently, PCR based techniques are potentially useful in the surveillance of the circulating subtypes. Applications of molecular genetics in public health is not only limited to communicable diseases. It has a potential value in the prevention and care of common cause of chronic ill health such as cancer, heart disease, stroke and diabetes. However, given the pressing need for the developing countries to overcome huge challenges posed by communicable diseases, and the constraints related to limited resources and facilities for research and development, non-communicable diseases are not the main focus of this discussion.

HIV Subtypes: moving target

HIV has shown a remarkable ability to exploit and adapt to changes in the social environment. At the molecular level, also, the virus is constantly changing. In order to map the genetic variation of HIV-1, scientists have classified different strains of the virus into three groups: M (main), O (outlier) and N (non-M, non-O)(*appendix 1*). The main group (M) is further classified into a number of subtypes, as well as variants resulting from the combination of two or more subtypes, which, according to UNAIDS/WHO (2002), is known as 'circulating recombinant forms' (CRF). Subtypes are defined as having genomes that are at least 25% unique. Eleven subtypes have been identified and a letter (subtype A or C and so on) designates each. When subtypes blend with each other (for example, when an individual is infected with two different HIV subtypes), and the resulting genetic blend successfully establishes itself in the environment, it is known as a CRF. So far, 13 CRFs have been identified.

To date, some subtypes have remained largely limited to certain geographic areas. Subtype C, for example, is widespread in Southern Africa, India and Ethiopia. Subtype B is common in Europe, the Americas and Australia (*ibid.*) but nearly all subtypes can be found in Africa, together with a number of CRFs. These unique genetic forms

of HIV are providing molecular epidemiologists with valuable tools for tracking the spread of the epidemic. The subtypes have been studied long enough for some key trends to be revealed. It follows that subtype C is the most common, accounting for approximately 50% of all new HIV infections. Subtype A is the second-most prevalent variant of HIV-1 and accounts for about 30% of HIV infections in East Africa, but 80% in West Africa (*ibid*).

In Eastern Europe, subtype A featured in the epidemic that began in Kaliningrad in 1995/96, while elsewhere subtype B spread among injecting drug users. Both variants have now re-combined into a new CRF, known as AB, which is spreading eastwards in Africa. Another recombinant form, CRF02_AG, is becoming prominent in West Africa – an area that has seen relatively stable HIV prevalence for years, but where the epidemic recently began expanding rapidly (in Cameroon, for example). There, over 30% of new infections now involve CRF02_AG. In China, three variants have been identified. Subtype E settled along the coast (likely because of the sexual liaisons of passing sailors), while subtype C probably arrived from India, and subtype B initially circulated among injecting drug users. There is now evidence that B and C have re-combined and are spreading northwards in China (*ibid*).

It remains uncertain whether the existence of different subtypes has important implications for the transmissibility or treatment of HIV. Some scientists have postulated, for example, that the predominant strain in Southern Africa is more aggressive than others. One study in the United Republic of Tanzania indicated that subtypes A and C might be more easily transmitted from mother to child. Another study claimed that female sex workers in Senegal were up to eight times more likely to develop AIDS when infected with subtypes C, D or G than with A. Studies elsewhere, however, have not confirmed such observations (*ibid*).

The good news is that all subtypes identified so far are clearly responsive to antiretrovirals. While some studies have found some variation in the ways different subtypes and CRFs respond to antiretrovirals, there are some studies that have found no such differences (Harris *et al*, 1993).

Further, clinical evidence on whether different subtypes have different therapeutic implications (for example, in the combination of drugs used or in dosages), awaits a substantial increase in clinical access to antiretrovirals among populations where subtypes other than B predominate. However, as well as variation between populations, HIV is constantly mutating within individuals, and this has important clinical and public health implications. Together with ‘natural’ variation, HIV genes also mutate in response to external pressures, such as the immune response a person’s body musters or the use of antiretroviral drugs.

DNA Diagnostics for the Identification of Drug Resistance Organisms

In recent years, DNA diagnostic has turned out to be of considerable value for the identification of organisms, which are difficult to isolate or culture, and there is more immediate application of this technology, which may be of considerable economic importance for many developing countries. Some of the genes that are responsible for drug resistance in important pathogens, including those responsible for tuberculosis, HIV/AIDS and malaria have already been characterized. Changes in the reverse transcriptase and protease genes of human immunodeficiency virus (HIV) confer resistance to the variants against a variety of antiretroviral drugs (see Tables 1 and 2).

Table 1: Protease Mutationsa

Drug	Drug target position in the protease gene														
	20	30	36	46	48	50	54	63	71	82	84	88	90	101	
Amprenavir															
Indinavir															
Nelfinavir															
Ritonavir															
Saquinavir															

- Major mutations: clearly associated with drug resistance.
- Minor mutations: add to the resistance caused by major mutations.
- Natural variants: natural variants of the virus that can add to drug resistance.

^aBased on Project Information on HIV Drug Resistance Tests. Available on the World Wide Web at <http://www.projinf.org/fs/GenoPheno.html>

Since 1995/96, when antiretrovirals were widely introduced, an increase in resistance mutations in newly infected people has been reported in the Americas and Europe. New multidrug-resistant strains are now being documented. The genetic variability of HIV is one reason vaccine development has been such a scientific challenge. Some potential vaccines may work only against particular subtypes, so subtyping has influenced vaccine testing.

In Thailand, for example, an experimental vaccine modified when molecular epidemiologists reported that the dominant subtype B had been replaced with another Subtype E –in a population of injecting drug users among whom the trial was to be conducted. The vaccine-makers modified the vaccine by including two vaccine components, targeting both subtypes. The hope now is that vaccine scientists can discover aspects of the virus that are consistent enough for a vaccine to provoke an effective immune response against multiple variants of HIV. If such viral features are found to exist, hope for a broadly effective vaccine grows. This research however is continuing.

Table 2: Reverse Transcriptase Mutationsb

Drug	Drug target position in the reverse transcriptase gene																
	41	65	67	70	74	75	103	115	116	151	181	184	188	210	215	219	333
3TC																	
Abacavir																	
AZT																	
AZT + ddI/ddC																	
AZT + 3TC																	
d4T																	
ddI / ddC																	
Delavirdine																	
Efavirenz																	
Nevirapine																	
Adefovir																	

- Major mutations: clearly associated with drug resistance.
- Minor mutations: add to the resistance caused by major mutations.

^bBased on Project Information on HIV Drug Resistance Tests. Available on the World Wide Web at <http://www.projinf.org/fs/GenoPheno.html>

Likewise, several genes are responsible for anti *M.tuberculosis* drug resistance, with catalase peroxidase gene (*katG*) being the most prevalent isoniazid-resistance gene. On the other hand, alterations (mutations) in the chloroquine resistance transporter gene (*Pfcr*) of *Plasmodium falciparum*, encoding chloroquine resistance transporter protein confer chloroquine resistance in laboratory strains of the parasite. Similarly, mutations in the dihydrofolate reductase (*dhfr*) and dihydropteroate synthase (*dhps*) genes encoding dihydrofolate reductase and dihydropteroate synthase enzymes of *Plasmodium falciparum*, confer SP and proguanil resistance to laboratory strains of the parasite.

Recent studies in Mali showed that there is stable relationship between rates of chloroquine resistant genotypes and in-vivo chloroquine resistance at sites where there are different population sizes, ethnic compositions and levels of drug resistance and malaria transmission (Djimde *et al.*, 2001).

Similar studies in Tanzania demonstrated that the resistance conferring mutation K76T of the *pfcr* gene in *Plasmodium falciparum* is positively selected for by drug pressure (Schneider *et al.*, 2002). This approach potentially appears to have a considerable value for public health surveillance of antimalarial resistance and may permit comprehensive mapping of resistance at country and regional levels without the need to carry out numerous repeated longitudinal efficacy studies. An array of robust and highthroughput molecular techniques are now available widening the ability to monitor rapidly large number of samples for drug resistance and to maintain regular surveillance of the emergence of resistant strains (Duraisingh *et al.*, 1998; Allouche *et al.*, 2000; Kirsten, 2002). This is likely to be an important addition to the public health measures directed at the control of many important pathogens. In the case of malaria, for example, in recent years, there has been a concerted scientific effort to assess the role of molecular markers of drug resistance on *in-vivo* clinical response to antimalarial drugs (Plowe *et al.*, 1997; Jelinek *et al.*, 1997; Alifrangis *et al.*, 2001a,b). However, a great deal more research is still required to assess the relationship between resistance markers and lack of clinical response.

Clearly, since the pattern of emergence of drug resistant pathogens varies widely between different countries, it is extremely important for every region of the developing world to pursue this research and to have access to this technology and, where this is not possible, to develop it. As information from the pathogen genome project continues to become available, it should be priority for countries to develop similar approaches for their own particular pathogens.

Plant Genomics Biotechnology, Human Health and Medicine

It is estimated that over the next 25 years, the world's population is likely to increase by about 2.5 billion people, with the big part of this projected growth occurring in developing countries (WHO, 2002). Consequently, food requirements in the developing world are expected to double by 2025. However, in recent years, there has been a decline in the annual rate of cereal production, such that, the present yield is far below the rate of population increase (*ibid*).

The genetic modification of plants has enormous potential value for improving the world's food supplies and the health of its communities. For instance, genetically modified maize has been successfully grown on a commercial basis in Spain for several years (Mahathir, 2002; Malisa *et al.*, 2002). The country accounts for 11% of the total European Union production of the crop. Additionally, the government has indicated in its Eighth Malaysian plan, that biotechnology will become a major initiative in the promotion of science and technology, research and development, and technological innovation to support Malaysia's overall strategy for sustainable growth in the knowledge-based economy. In the 2000/2001 season, an estimated 300 large-scale commercial farmers produced 95% of South Africa's cotton crop, and the other 5% was produced by about 3,000 small-scale farmers. In Kenya, increasing demand for maize coupled with ineffective disease and pest control measures have necessitated the adoption of biotechnology to produce maize strains with a high capacity for disease resistance and tolerance to adverse weather and environmental conditions (Mugo, 2002).

The Insect Resistant Maize for Africa (IRMA) project aims to increase maize production and food security through development of insect resistant maize strains in Africa (Kirsten, 2002).

Some of the potential advantages of genetically modified (GM) plants are: enhancement of the nutritional value of crop species, increased nutritional content of foods, decreased allergenicity and conferment of resistance to pathogens. A rather direct application of plant genomics in human health is through its potential for the control of diseases in human. Through genetically modified plants, it is hoped that it will be possible to produce edible vaccines which are cheaper than conventional vaccines and which can be grown or freeze dried and shipped anywhere in the world.

Applications of Biotechnology in Health and Medicine: Potential Risks and Hazards

The advance of biotechnology in the food arena presents consumers worldwide with new challenges and questions of both a technical and an ethical nature. The spectrum of safety issues concerning GM food is extremely wide, encompassing: the evolution of new or increased allergic reactions in humans by animals used as food source, toxic effects on the environment from the production of new biologically active proteins, adverse effects to other animals from changes in behavior; alterations in the ability of an animal to act as a human disease reservoir, the effect on the ecosystem of releasing genetically modified subjects; the potential effects of introducing foreign DNA into plants including the use of bacterial antibiotic resistance genes as selection markers, the risk that transgenic DNA is transmitted to the host and might lead to genetic alteration of the host and the possibility that microorganisms that inhabit gastrointestinal tract or soil might acquire transgenic DNA. Clearly, regulation of the safety of GM foods and live modified organisms (LMOs) is of great importance for global health. There is a need, therefore, for the coordination of the long-term strategic planning of food safety initiatives, nationally, regionally and globally. This can only be achieved through support from governments in working towards integrating food safety as one of the essential public health functions with the goal of developing sustainable integrated food safety systems for health risk reduction along the entire food chain, beginning with primary production in agriculture and following through to the consumer.

The most serious safety issue of an ethical nature is probably the potential misuse of the biotechnology and genomic knowledge on bioterrorism. Information, which is being derived from the pathogen genome projects, is potentially open for abuse and misuse. In particular, identification of virulence genes, understanding of the mechanisms by which pathogens evade host defense, and the increasing ease with which it is possible to manipulate the genome of bacteria and viruses provide a potentially wide range of biological ammunitions. Although globalization of food trade may offer consumers a wider variety of good quality food that are accessible, affordable and safe, when poorly managed, it can present huge risks to human health because unsafe food originating from one country is likely to cause public health disaster in the other. Effective regulatory mechanisms to monitor and control commercial and medical application of biotechnology in the public interest are now well established in many developed countries. Conversely, in many of the developing countries, such mechanisms are lacking and hence, there is an urgent need for these countries to consider and build on international principles in establishing their own regulatory mechanisms.

Clearly, tackling the potential challenges of biotechnology in foods and its globalization requires effective regulatory and control mechanisms and implementation of the targets agreed upon in international summits and conferences especially the Cartagena protocol on biosafety. The protocol is a supplementary agreement to the Convention on Biological Diversity, and it aims to ensure the safe transfer, handling and use of LMOs resulting from modern biotechnology and which may have adverse effects on biological diversity, taking also into account risks to human health. Ultimately, implementation of the protocol's guidelines will markedly reduce the risks associated with globalization of food trade.

Applications of Biotechnology in Health and Medicine: Ethical Issues

As biotechnology becomes increasingly integrated into medical research, ethical issues related to its application raise contentious challenges and concerns. Unless the ethical issues are carefully addressed in an acceptable manner, it will be difficult for the potential health benefits of this new technology to be realized. Although most of the ethical issues raised by genomics for developing countries do not differ from those applied in other areas of biology and medicine, such as informed consent, confidentiality and stigmatization and discrimination, they require some spe-

cific consideration in the context of genomics, and cannot simply be addressed by standard approaches in medical ethics for the following reasons: Firstly, since genetic information about individuals can potentially be highly predictive of their future health, it has the potential both to stigmatize them and to be used by others such as potential employers and insurers as basis for discrimination.

Secondly, the appropriate uses of our new genetic knowledge and capacities, the potential for their misuse or abuse, as well as the kind of responses needed to prevent such misuse or abuse, all depend on social, political economic and cultural integrities. As a rule that clearly appears in the Declaration of Helsinki and in the laws of many countries, human subjects should strictly not be enrolled in any research without their free and informed consent. Except for some cultural contexts, that lack any strong tradition or practice of individual consent, where it may be more common for community leaders to give consent for research programmes in their community, individual consent become ultimately necessary. While it is appropriate to respect these cultural practices and to seek the agreement of properly identified community leaders to undertake research programmes, it should not substitute securing the informed consent of individual participants as well. Due to low educational levels in developing countries, investigators conducting genetic research in these countries have an obligation to ensure that information is provided in a format that is understandable to participants, and appropriate to their educational levels and cultural context.

One aspect in which genetic information is different from other health care information is that it is typically not just about a particular individual who has been screened or tested, but also involve other family members of that individual. Consequently, confidentiality of genetic information to prevent all possible discriminations and stigmatization should adequately be addressed. Generally, relevant ethical principles in genetic testing include: respecting the self determination of individuals and protecting those with diminished autonomy; giving highest priority to the welfare of persons and maximizing benefits to their health; avoiding and preventing or at least minimizing harm to persons; treating persons with fairness and equity; respecting human diversity; respecting people's basic intelligence regardless of their knowledge; prevention of unfair discrimination or favouritism in employment, insurance or schooling based on genetic information etc.

Obviously, genetics and biomedical technology opens vast new avenues for research and can provide human kind with much needed therapeutic tools. Nonetheless, where human life and dignity are at stake, technology cannot be left on its own to govern ethics.

The Future Direction of Biotechnology in Health and Medicine

Successes of modern molecular genetics are based firmly on classical genetics, which evolved after the discovery of the work of Mendel at the beginning of the 20th century. Remarkable sophisticated series of new technologies that followed thereafter brought about revolution in genetics leading to the molecular era of genomics. It is now clearly understood that the characteristics of all living organisms reflect the complex interaction between their genetic make up, their environment, and the long history of the milieu in which they are raised, i.e. the nature-nurture complex. Consequently, it is recognized that many of the biological functions, which result from this interplay, will ultimately be explained in terms of biochemical mechanisms, which in turn, reflect the activity of the genes that regulate them. By using these technologies, the study of diseases at cellular and molecular levels has been possible, and already a considerable amount of progress has been made on diseases of public health importance. Some of these include:

- A candidate vaccine for *Plasmodium vivax*, the main type of malaria in India, has been identified by a recent collaborative effort between Indian researchers at the International Centre for Genetic Engineering and Biotechnology in New Delhi and the Malaria Vaccine Initiative.
- Clinical trials at the University of Nairobi, Kenya and Oxford University, UK, of a DNA-based AIDS vaccine candidate designed specifically for Africa.
- Creating a new designer mosquito that cannot carry the malaria parasite, one of the biggest killers in the developing world.

- Cuba has developed a meningitis B vaccine at the Carlos J. Finlay Institute, attesting to the potential of biotechnology in developing countries.
- Rapid identification of a class of anti-malarial drugs that have the potential to be effective against multi-drug-resistant parasites, as well as being inexpensive and stable. A combination of malaria parasite DNA sequencing, bioinformatics (use of computer technology to store, analyze and interpret biological data), and data mining (searching for comparative genomic data) has been instrumental in the creation of these drugs.
- Scientists are using DNA technology to produce vaccines that can be incorporated into potatoes and other vegetables, and fruits, against hepatitis B, cholera, measles, and human papilloma virus (associated with cervical cancer, a common malignancy in women in sub-Saharan Africa), allowing the vaccines to be ingested as part of a meal.
- The diagnosis of leishmaniasis and dengue fever, both pandemics in some Latin American countries, has already been improved by the use of polymerase chain reaction techniques – one of the basic techniques in DNA research.
- Two new types of vaccines derived from genetic research have been developed against tuberculosis, which is spreading in both developing and developed countries. Clinical trials of one of these vaccines have already started.

Recently, almost the complete sequence of 3×10^9 base pairs of the DNA, which constitute human genome, has been determined (Venter *et al.*, 2001). Moreover, remarkable progress has been made toward sequencing the genomes of a broad range of human pathogens, the work that has direct application for the prevention, diagnosis and management of communicable diseases particularly in developing countries. The rapid advances in genomics over the next few years may revolutionize the entire approach in the medical research and practice as results of its potential value in controlling some of the most intractable diseases of human kind. As we are now moving away from genomics towards functional (post) genomics, the vast databases that are emerging from this field, encompassing both sequence variation and expression of genes, and the structure of their protein products, will require major developments in computational biology for their analysis and interpretation into functional terms.

Functional genomics requires integration of variety of different technologies such as annotation, proteomics, transcriptomics, micro array (DNA chip), bioinformatics etc. Clearly, participating in this area of research requires the associated development of bioinformatics to store, analyze and interpret the huge quantities of data that are generated. These data are being released freely into the public domain, and a number of sophisticated algorithms and other software resources are equally available via the Internet free of charge. As technology advances, research and development (R&D) remain increasingly important for solving public health problems in the developing countries. However, the high cost involved in R&D aimed at the discovery of therapeutic agents and other public health products has typically limited such researches to the developed world, ultimately leading to the neglect of health needs of the developing world. Although partnerships, including public-private, are seen in the global R&D strategy as an appropriate way to address the unfinished agenda of infectious diseases in poor countries, experience has shown that this works only with large companies, potentially narrowing the likelihood that poor countries can benefit from any such partnerships. The only way to circumvent the R&D problem, remain the need for the poor countries to strongly encourage and invest on basic science which aims at discovery, as opposed to their current focus on predominantly epidemiological researches.

WEHAB: Africa's way forward in Biotechnology

The key resolutions and recommendations of the African Biotechnology Stakeholders' Forum (ABSF) were mapped out following the recently concluded world summit on sustainable development (WSSD) with implications for the development and applications of biotechnology in Africa. The five priority areas targeted in the implementation plan for global commitment to combat poverty for sustainable development are water, energy, health, agriculture and biodiversity (WEHAB). Political commitments pledged by world leaders and heads of governments included: to give priority to the fight against chronic hunger, malnutrition, communicable and chronic diseases; to increase access to

basic requirements in health care, food security, energy and environmental protection; to use modern technology to catalyze development; and, to ensure that technology transfer matches human resource development through education and training.

The major challenges to development and application of biotechnology in Africa have been identified thus: lack of effective policy frameworks to enhance and regulate biotechnology development and application; the need to develop appropriate partnerships for sustainable use of biotechnology; the need to lobby national governments to allocate more resources to build and maintain effective capacity for biotechnology and, the development of effective communication strategies and structures to enhance understanding of biotechnology and its application in problem solving. As a way forward, ABSF and the Biotechnology Information Center pledged to play a catalytic role in the follow-up process by facilitating dialogue among policy makers and providing stakeholders with up-to-date information on development in biotechnology globally to enable Africa achieve her dreams in biotechnology.

Conclusion

Global strategies like the World Trade Organization (WTO) TRIPS have considerable effects on the future of biotechnology and culmination in globalization. WTO TRIPS agreement establishes minimum standards and guidelines for the protection of intellectual property right. Developed countries had to amend their respective patent acts to conform to the TRIPS standards by 1996, developing countries by 2000, and least developed countries by 2006 (recently, after DOHA meeting, by 2016). Under TRIPS, all its 142 (as of June 2001) member countries have to provide patent protection for a minimum of 20 years, and these patent protections have to be extended equally to all patented products, whether imported or locally produced. Although patents are aimed at encouraging innovation, there is unresolved controversy that DNA patenting is retarding rather than stimulating both scientific and economic growth (Williamson, 2001; Barton, 2001). The monopolies awarded by patents on genes as novel chemicals are not in the public interest and may in the long run render some of important biotechnological tools unavailable for the poor countries. This unsatisfactory situation has important implications for the health of developing countries.

Although the current applications of genomics for clinical practice in developing countries are very limited, this completely new field of biological sciences has enormous potential for improving health care, and there is no doubt that genetics will assume an increasingly important role in medical research and health care over the next few decades. It is, therefore, essential that, as this field evolves, the developing countries do not get left behind the same way they lagged behind in the computer revolution.

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