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A STUDY ON APPLICABILITY OF BIOTECHNOLOGY TO DEVELOPMENT IN THE CARIBBEAN: OPPORTUNITIES AND RISKS

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ABSTRACT

The present study analyzes the potential opportunities and risks involved in employing biotechnologies in the Caribbean region. This information would support developmental policies in the areas of food security, climate change and poverty reduction. The report provides a brief overview of biotechnology development, covering industrial and other microbial biotechnologies, tissue culture and molecular biology. Details of opportunities and risks of biotechnology development are provided for agricultural, industrial, environmental, industrial and medical biotechnology, with information on the global agreements for regulation of genetically modified organisms. The rest of the report analyzes the Caribbean situation. Biotechnology applications, opportunities and risks in the Caribbean are described in detail, with focus on industrial and agricultural biotechnology, and including climate change and constraints to biotechnology development. The report closes with a discussion of the applicability of biotechnology to the region in terms of agricultural, industrial, environmental, medical and marine biotechnology. Conclusions and recommendations are provided. The main conclusion of the study is that there is an urgent need for development and use of biotechnology in the Caribbean, especially in non-agro-biotech sectors, to address food security, climate change, poverty, environmental degradation, among other issues. In so doing, countries must take advantage of the opportunities presented by biotechnology to gain competitive advantage and benefits, while at the same time put measures in place to reduce or remove associated risks. This must be done taking into consideration economic as well as social and cultural issues.

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Acronyms

AFLP	Amplified Fragment Length Polymorphism
CAC	Codex Alimentarius Commission
CARDI	Caribbean Agriculture Research and Development Institute
CARICOM	Caribbean Community
DNA	Deoxyribonucleic Acid
ECLAC	Economic Commission for Latin America and the Caribbean
EU	European Union
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GM	Genetically Modified
GMOs	Genetically Modified Organisms
IPPC	International Plant Protection Convention
ISPMs	International Standards for Phytosanitary Measures
LMOs	Living Modified Organisms
MDCs	More Developed Countries
MEAs	Multilateral Environmental Agreements
mRNA	Messenger Ribonucleic Acid
OIE	World Organization for Animal Health
OLADE	Latin American Energy Organisation
PCR	Polymerase Chain Reaction
PRA	Pest Risk Analysis
R & D	Research and Development
RAPD	Randomly Amplified Polymorphic DNA
rDNA	Recombinant DNA
RFLP	Restriction Fragment Length Polymorphism
SIDS-POA	Small Island Developing States Programme of Action
SNP	Single Nucleotide Polymorphism
SPS	Sanitary and Phytosanitary
SSR	Single Sequence Repeat
STI	Science, Technology and Innovation
TBT	Technical Barriers to Trade
TRIPS	Trade-Related Aspects of Intellectual Property Rights
UNEP	United Nations Environment Programme
UWI	The University of the West Indies
WHO	World Health Organization
WTO	World Trade Organization

I. INTRODUCTION

The Caribbean region consists of mainly island States extending from the Bahamas in the north, to Guyana and Suriname in the South American continent, and including Belize in Central America. The islands are characterised by varied topographies, geology, flora and fauna, and high population densities especially in coastal areas. The non-island States of Suriname, Guyana and Belize are among the least densely populated in the world. Caribbean States depend on a rich diversity of plant genetic resources for nutrition, health and well-being (UNEP, 1999; ECLAC, 2008a; ECLAC, 2010a).

For 2009, the population of Caribbean Small Island Developing States (SIDS) was estimated at 38,162 million, with generally stable population growth, decreasing birth rates and crude death rates, improving health conditions and increasing urbanization. Country poverty assessments from 1996 to 2006 show relatively high poverty levels (average poverty level, excluding Haiti, is 26%), with highest poverty levels in Haiti (76%) and lowest in the Bahamas (9%). In 11 States, poverty levels exceed 20%. The poor generally inhabit rural areas, but urban poverty is increasing. During 2003-2008/2009, unemployment rates ranged from 7.6% to 14.2% in the Bahamas; 7.4% to 11.0% in Barbados; 8.2% to 12.9% in Belize; 9.8% to 11.7% in Jamaica; and 4.6% to 10.5% in Trinidad and Tobago. A major concern is high unemployment among youths, particularly female unemployment (UNEP, 1999; Statistical Institute of Belize, 2002-2008; ECLAC, 2004; Barbados Annual Statistics Digest, 2009; Jamaica Statistical Digest, 2009; Trinidad and Tobago Central Statistical Office, 2009; ECLAC, 2010a; Bahamas Department of Statistics 2010/2011).

Agriculture, mining and commercial services are the main contributors to Gross Domestic Product (GDP) in Caribbean States. Trinidad and Tobago's economy is driven by its oil and gas sector; mineral sectors are important to Jamaica and Suriname; agriculture is important in Belize and Guyana, and most other Caribbean nations are service-oriented. The dominance of the tourism sector in the Caribbean is evidenced by its contribution to GDP (up to 73.5% in Antigua and Barbuda-2008), employment (more than 20% of the region's workforce-2008) and foreign exchange earnings (US$ 28.4 billion for the region-2008). Agriculture is a significant export earner and livelihood means in some countries, with sugar, rice and bananas as important crops (CARSEA, 2007; ECLAC, 2010a,b).

The Caribbean relies heavily on few preferential markets for major exports. The European Union (EU), United States and Canada account for 68% of Caribbean Community (CARICOM) exports. Intraregional exports are dominated by the Bahamas, Barbados, Belize, Guyana, Jamaica, Suriname and Trinidad and Tobago also known as More Developed Countries (MDCs) between 2000 (92.3%) and 2007 (93.6%). Significant quantities of imports are sourced extraregionally, the MDCs contribution to intraregional imports averaged 77.8% between 2000 and 2007 (ECLAC, 2010a).

Most Caribbean countries generate their energy mainly from fossil fuels, and Caribbean per capita commercial energy consumption exceeds that in the Indian Ocean and South Pacific island States by a factor of three to four. Sustainable energy sources play a small role in national energy strategies. Renewable energy technologies most feasible for region are: hydropower; modern biomass conversion; wind and solar energy; ocean thermal energy conversion; wave and geothermal energy. Caribbean countries and regional institutions are starting to take up the challenge of making the transition to sustainable energy. The main regional institutions involved in sustainable energy are the Caribbean Energy Desk established within the CARICOM Secretariat, Latin American Energy Organization (OLADE), the regional body of electric utilities, the Caribbean Renewable Energy Development Programme/German Technical Cooperation programme of the German technical assistance agency, and the Global Sustainable Energy Islands Initiative. Several countries (Cuba, Jamaica, Saint Kitts and Nevis) are developing policies and strategies for sustainable energy pathways. There are an increasing number of donor-funded initiatives, reflecting the global policy and focus on climate change impacts and energy security, many of which aim to generate private sector investment in renewable energy: An African, Caribbean, Pacific Energy Facility; Biofuels Agreement; Caribbean Renewable Energy, Energy Efficiency and Bioenergy Action Plan;

Caribbean Renewable Energy, Energy Efficiency and Carbon Finance Facility; Eastern Caribbean Geothermal Development Project; and the Sustainable Energy and Climate Change Initiative (UNEP, 1999; ECLAC, 2010a).

External factors significantly impact on the growth of Caribbean economies: hurricanes and natural disasters have slowed economic growth in some islands; economic growth in Europe and the United States has supported the region's tourism sector; and higher global mineral prices have assisted Caribbean exporters. The region has also benefited from preferential trade with the United States, Canada and the EU (UNEP, 1999; ECLAC, 2010a). The global economic and financial crisis, which began in the economies of North America and Europe in 2008, sparked abrupt declines in exports and commodity prices and reduced trade and investment, slowing growth in developing countries. As the crisis deepened, government stimulus measures began to curb the slide in the economic activity and lessen the impact of global job losses (UN, 2010). The impact of the global crisis on Caribbean economies is discussed in ECLAC (2010b).

The Caribbean environment is impacted by human activities and natural disasters. The small size and rugged terrain of most islands limit the availability of land for competing uses. The impacts include land degradation, unplanned infrastructure developments, and inadequate waste disposal. Land degradation, due to poor land management practices (slash and burn agriculture, uncontrolled livestock grazing on fragile lands, poor road construction and unplanned or poorly planned settlements in landslide-prone areas) is of great concern. It reduces productivity of agricultural land and coral reefs, potentially impacting on food security. Inappropriate land use has led to the irretrievable loss of land for agriculture, watershed protection and biodiversity conservation. Over 70% of dry lands in agriculture suffer degradation, which could worsen as agriculture extends into marginal areas. The declining interest in sustainable agriculture has led to insufficient food production to satisfy domestic demand, and high food import bill. Freshwater resources in Caribbean islands, which are considerably less than other oceanic groups, are also highly threatened (UNEP, 1999; ECLAC, 2010a).

Annual deforestation rates range from 0.8% to 7.2%, destroying biodiversity and soil fertility. Land use practices and land tenure of agricultural lands are key issues to be addressed in forest conservation and management. Caribbean marine and coastal environments are important natural resources (provide food and medicinal resources, protect coastal settlements from storm damage, and generate income from tourism). However, the coastal ecosystem, with its high biodiversity, is extremely fragile and vulnerable to human impacts. Caribbean coral reefs are already greatly degraded, having lost about 80% of living coral cover over the last 20 years. This decline has implications for reef fisheries and shoreline protection. Both near-shore pollution and offshore harvesting further increases the risk of collapse of the vast coastal ecosystem. Loss of important coastal nursery areas (mangroves and sea-grass beds) may contribute to decline in fish stocks (UNEP, 1999; CARSEA, 2007; ECLAC, 2010a).

While air quality is not currently a major concern in Caribbean States, increasing urbanization, motor vehicles and industrialization is likely to impact on air quality in the future. Caribbean air quality is also affected by transcontinental movement of particulates from Africa. Apart from air quality, urbanization can contribute to other environmental problems: land use, marine and coastal deterioration, water use and pollution, and solid and hazardous waste management. In the Caribbean, waste management is largely unsatisfactory, and systems (storage, collection, transportation, processing, recovery and disposal) have not kept pace with increasing demand. The resulting impacts on the terrestrial, coastal and marine environment, biodiversity and human health, have been severe. Pollution prevention and waste management therefore are critical issues in most Caribbean States (UNEP, 1999; ECLAC, 2010a).

Most Caribbean islands lie within the hurricane belt and are vulnerable to damage from hurricanes or storms. Other natural hazards affecting the region are earthquakes, volcanic eruptions, floods, landslides and tsunamis. Disasters are so frequent and all-encompassing that they have resulted in massive economic, social and ecological costs. The environmental effects of natural disasters are multiple and complex, and thus, considerable attention is being paid to disaster preparedness, assessment and mitigation in the insular Caribbean. The impacts of recent large scale (fatalities and damages) natural disasters in region has led to renewed interest by national governments and international donors in better managing risk (UNEP, 1999; ECLAC, 2010a).

Climate change is a major threat to the Caribbean due to the vulnerability of small island ecological and socio-economic systems. The impacts of climate change in the Caribbean include sea level rise, increase in frequency and intensity of hurricanes, increase in frequency and severity of droughts, and increase in temperatures. Climate change will affect the region's agriculture, water resources, tidal zone ecosystems, fisheries and health. Potential health impacts will be linked to higher temperatures and spread of tropical disease vectors (UNEP, 1999; ECLAC, 2009a).

The interdependence of economy and ecology is evident throughout the region. The problems of ecological fragility, close interdependence of economy and environment, and vulnerability to hazards require countries to be vigilant in maintaining their natural resources if sustainable economic growth is to be achieved (UNEP, 1999).

In addressing sustainable development issues, the Caribbean region has embarked on relevant global multilateral environmental agreements (MEAs) such as the United Nations Framework Convention on Climate Change and the Global Programme of Action for Protection of the Marine Environment from Land-based Activities. It is, however, difficult to determine the effectiveness of global MEAs in promoting national legislation to protect the environment. Generally, there is limited enactment of national laws to facilitate compliance with the obligations of global MEAs. Similarly, there is limited assessment of the impact and effectiveness of regional MEAs. However, the effects of regional MEAs are more tangible at the level of regional programming. Additionally, several regional, hemispheric and global non-binding agreements and programmes help to guide regional environmental programming. Of these, Agenda 21 and the SIDS-POA have had a profound impact on promoting sustainable development in the region. The Mauritius Strategy for the Further Implementation of the Barbados Programme of Action for Small Island Developing States recognizes science, technology and innovation (STI) as a cross-cutting issue for all sectors involved in sustainable development. It calls for more action in: incorporating STI into national strategies, promoting and protecting traditional knowledge; reviewing STI related to environmentally-sound technologies and sustainable development; using STI and indigenous technology to reduce environmental risk; and providing a mechanism for cooperating and sharing regional STI experiences (UNEP, 1999; ECLAC, 2010a).

Biotechnology has a critical role to play as a tool to help provide solutions for the many global challenges (Reynolds, 1999). To meet these challenges, and capitalise on the wealth of their resources, Caribbean island countries have resorted to the systematic application of biotechnology (ECLAC, 2008a). The present study builds on a previous review of the origins and development of biotechnology in the Caribbean (ECLAC, 2008a) and seeks to determine the potential risks and opportunities in employing biotechnologies in the region. It is expected that this information would support developmental policies in the areas of food security, climate change and overall address poverty reduction. In this regard, the present report provides: a brief overview of biotechnology development; details of the opportunities and risks of biotechnology development; a description of biotechnology in the Caribbean, including constraints for development; and a discussion of the applicability of biotechnology to the region, with conclusions and recommendations for further applicability of biotechnologies.

II. BIOTECHNOLOGY DEVELOPMENT

The United Nations Convention on Biological Diversity defines biotechnology as "Any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use." Red biotechnology applies to medical applications, such as designing organisms to produce antibiotics, and engineering genetic cures by genomic manipulation. Green biotechnology refers to agricultural applications, such as improvements in plant selection, and designing transgenic plants to withstand various stresses. White biotechnology refers to industrial applications such as designing organisms to produce useful chemicals and using enzymes as industrial catalysts to produce valuable chemicals or destroy hazardous ones. Blue biotechnology describes marine and aquatic applications (ECLAC, 2008a,b; 2009b).

Early biotechnology developments included: fermentation of fruit juices into wine; conversion of milk into cheese; and use of yeast in baking. Modern biotechnology has its roots in Mendel's nineteenth century investigations of genetic inheritance in plants. In 1953, Watson & Crick identified the double helix structure of deoxyribonucleic acid (DNA), which launched the biological revolution to decipher the genetic code. Modern biotechnology uses biomolecular techniques to modify the genetic information to transfer genes from one organism to another to emphasize desired traits. This genetic manipulation or "genetic engineering," produces a genetically modified organism (GMO). The techniques are used also in new and traditional industries, from long-established commercial uses (brewing, vaccine production, and pest control) to genetic engineering (Reynolds, 1999; FAO, 2003; ECLAC, 2008b). The main areas of biotechnology are: industrial biotechnology; tissue culture; and molecular biotechnology.

A. INDUSTRIAL BIOTECHNOLOGY

1. Fermentation technology

Fermentation is the oldest biotechnological process linked with settled agriculture. It is an anaerobic cellular process in which organic foods are converted into simpler compounds and chemical energy is produced (http://www.biology-online.org/dictionary/Fermentation). The chemical reactions are caused by prokaryotic unicellular (bacteria and cyanobacteria) and multicellular (cyanobacteria) micro-organisms, and eukaryotic unicellular (yeast and algae) and multicellular (fungi and algae) micro-organisms. In 1897, Buchner discovered that enzymes extracted from yeast converted sugar into alcohol (ECLAC, 2008a,b; 2009b).

2. Enzyme technology

Enzyme technology involves the application of enzymes in industry, agriculture and medicine. Although the earliest documented reports of enzyme application were in the late 1800s, true industrial enzyme application began in the 1960s. Most enzymes used in industrial biotechnological applications are derived from specific fungi such as *Aspergillus*, and bacteria such as *Bacillus* (ECLAC, 2008a,b).

Enzymes are proteins and natural biocatalysts, produced by living organisms to accelerate and sustain chemical reactions necessary for life. Over 3000 enzymes are known to exist. They can be immobilized (linked to an inert support material without loss of activity), which facilitates their reuse and recycling (ECLAC, 2008a,b).

Enzymes have many uses: proteases (detergents, digestive aids, cheese-making, biomedical), cholesterol esterase and oxidase (monitor serum cholesterol levels), glucose isomerise (manufacture high-fructose syrups), glucose oxidase (monitor blood/serum glucose levels), pectinases (juice/wine clarification, coffee bean fermentation), glucanases (beer-making, degradation of haze polysaccharides), hemicellulases (baking, brewing, neutraceutics), and amylases (glucose production, brewing) (http://www.odofin.com.english/enzyme%20technology.htm).

3. Other microbial technologies

This includes a range of microbial biotechnological uses, such as the use of biological organisms to: improve plant growth; biologically control pests; improve nitrogen fixation; aid in absorbance of soil nutrients; aid in composting; safely treat and dispose of sewage and other biological wastes; and aid in creating energy using a range of biomass material (biogas etc.).

B. TISSUE CULTURE

In tissue culture, tissue fragments are cultured in an artificial environment. Cultures may be a single cell, population of cells, whole or part of an organ. 'Tissue culture' commonly refers to the culture of animal cells or tissues, and 'plant tissue culture' refers to plants. More recently, 'tissue culture' (*in vitro* growth of eukaryotic cells) is used interchangeably with 'cell culture' to specify the *in vitro* culture of sperm donor cells. 'Tissue culture' also refers to the culture of tissue fragments (explant culture) or whole organs (organ culture). Tissue culture is used as an economic tool for micropropagation of food and ornamental plants worldwide (ECLAC, 2008a,b; 2009b), but also is used in dihaploid breeding exploiting somaclonal variations, *in vitro* conservation of genetic resources, development of transgenics, or the production of a range of vaccines.

C. MOLECULAR BIOTECHNOLOGY

1. Recombinant Deoxyribonucleic Acid (rDNA)

DNA is the genetic material that codes for the biological information to recreate an organism. It synthesizes protein by transcription into messenger ribonucleic acid (mRNA), and translation into polypeptides, and is the basis of diversity. Since 1972, genes for many traits have been identified. The sharing of DNA between individuals of the same species occurs naturally by sexual reproduction. However with genetic engineering, DNA from different species may be combined (rDNA), by-passing barriers to sexual reproduction and hence transcending natural species barriers. A genetically-modified organism is therefore a transgenic (ECLAC, 2008a,b; 2009b). The features of rDNA technology are:

(a) Modification of nuclear and cytoplasmic genomes

(b) Modification of genes through a parasexual process

(c) Creation of novel pathways

(d) Changing the expression of a gene (gene silencing)

(e) Faster process than plant breeding

Traditionally, rDNA technology was limited to transferring single or small number of genes, allowing manipulation of single traits, but it is increasingly becoming possible to manipulate a range of traits or pathways using this technology. Also many stages in transformation are unpredictable, with dubious results subject to public opinion. Next-generation biotechnologies, such as omics, might compensate for present-day rDNA technology shortcomings. Other improvements in rDNA are: gene targeting by microinjection and homologous recombination appropriate for animals; development of markerless transgenic plants; genetic use restriction Technology or biological containment of transgenes; minimization of somoclonal variation; full copy integration; proper gene expression; control of the unpredictable expression of transgenes; and more stable transgenics (ECLAC, 2009b).

2. Molecular markers

A molecular marker is any kind of molecule indicating the existence of a chemical or physical process, and is used to identify a particular sequence of DNA (ECLAC, 2008a,b; 2009b). The most common markers are:

(a) Restriction Fragment Length Polymorphism (RFLP)

(b) Amplified Fragment Length Polymorphism (AFLP)

(c) Single Nucleotide Polymorphism (SNP)

(d) Single Sequence repeat (SSR)

(e) Randomly Amplified Polymorphic DNA (RAPD)

(f) Isozymes

RFLP, SSR and SNP markers are used extensively and have several advantages: they are co-dominant and unaffected by the environment, any DNA source can be analysed, and many markers can be mapped in a population not stressed by phenotypic mutations. The main drawback to RAPD markers is their dominance and do not allow scoring of heterozygous individuals. The weakness of isozyme markers is that each protein scored may not be expressed in the same tissue and at the same time of development, thus requiring several samplings of the population (ECLAC, 2008a,b).

III. BIOTECHNOLOGY: OPPORTUNITIES AND RISKS

The main applications of biotechnology are in agriculture, industry, environment and medicine (including forensics); with much discussion currently focused on agricultural applications, and, to a lesser extent, on biomedical issues (ECLAC, 2008a). The benefits of biotechnology (ECLAC, 2009b) are:

(a) Development of new crop varieties, helping to adapt to climate change, dealing with disease and pest resistance, and promoting food security

(b) Development of new drugs

(c) Disease diagnosis in humans, animals and plants

(d) Forensic applications

(e) Bioremediation (waste treatment)

(f) Gene therapy to correct hereditary conditions

A. AGRICULTURAL BIOTECHNOLOGY

According to ECLAC (2008a), the two main areas of agricultural biotechnology development are disease resistance and crop improvement. The use of GMOs in agriculture has benefits (productivity, environment and human health) but may pose potential risks (environment, human health and socio-economy) in an unregulated environment (FAO, 2003). This is elaborated in the following text.

1. Potential benefits of GMOs

The main benefits of GMOs are:

Agricultural productivity:

(a) Improved stress resistance. Improved crop resistance to pest outbreaks and severe weather would decrease the risk of crop failure

(b) More nutritious staple foods. The insertion of certain genes into crops can increase their food value. The genes responsible for producing the vitamin A precursor were inserted into rice plants resulting in grains with higher vitamin A levels termed Golden Rice. As rice is consumed by over 50% of the global population, it has potential for addressing the problem of vitamin A deficiency in developing States. Other bio-fortification products are also being developed

(c) More productive crop plants and animals. Genes are inserted into cattle to raise milk yield

Environmental:

(a) Increased productivity. With improved productivity from GMOs, farmers could reduce the marginal lands being cultivated in the future

(b) Reduced environmental impact of food production and industrial processes. Genetically engineered pest- and disease-resistance could greatly reduce the chemicals required for crop protection. Maize, cotton and potato crops need not be sprayed with bacterial or any other form of insecticide as the insecticidal agent is produced by the crops. Trees with lower lignin content are being developed, reducing the need for noxious chemicals in pulp and paper production. These developments could reduce impact on the environment and workers' health

(c) Rehabilitation of damaged or less fertile land. In developing countries, large areas of agricultural land have become saline due to unsustainable irrigation practices. Genetic modification could produce salt-tolerant varieties of crops and trees, and also varieties for rehabilitation of degraded land

(d) Bioremediation. Rehabilitation of damaged land, possibly through organisms developed to restore nutrients, degrade pollutants and maintain soil structure.

(e) Longer shelf lives. Genetic modification of fruits and vegetables can reduce spoilage during storage or transport to markets, potentially expanding trade opportunities and reducing massive wastage in transport and supply.

(f) Biofuels. Organic matter can provide energy, and plant material fuel (biomass) has huge energy potential. Sugarcane waste can provide energy in rural areas, and it is possible to breed plants for this purpose.

Human health:

(a) Investigation of diseases. Genetic fingerprinting of animal and plant diseases is already underway, allowing for differentiation of disease-carryings and vaccinated ones, thus preventing unnecessary killing of healthy animals.

(b) Vaccines and medicines. The use of molecular biology to develop vaccines and medicines for farm animals is successful, with great promise for the future. Plants are being engineered to produce vaccines, proteins and other pharmaceutical products, by "pharming."

(c) Identification of allergenic genes. Molecular biology could also be used to characterize and remove allergens.

2. Potential impacts

The main arguments against GMO use include:

Environmental:

(a) Gene escape. Genes can pass on to other members of the same species and possibly other species at the gene, cell, organism and ecosystem levels. Although research is inconclusive, there is scientific consensus that once widely released, recalling transgenes or foreign DNA sequences with debatable scientific safety, will not be feasible

(b) Gene mutation. It is unknown whether artificial insertion of genes could destabilize an organism and encourage mutations, or whether the inserted gene will be stable over generations.

(c) Accidental switching on of 'sleeper' genes and silencing of active genes. Organisms contain genes that are activated under certain conditions. With the insertion of a new gene, a "promoter" gene is also inserted to switch it on. This could activate a "sleeper" gene in inappropriate circumstances. Sometimes the expression of genes is "silenced" by unknown interactions with the inserted gene. This is relevant in long-lived organisms such as trees

(d) Interactions with wild and native populations. GMOs (farmed fish) could compete or breed with wild species. GM crops could pose a threat to crop biodiversity, especially in areas that are centres of origin of the crop. GM crops also could compete with and substitute traditional varieties and wild relatives, which were bred, or evolved to cope with local stresses

(e) Impact on biota. Potential risk to non-target species (birds, pollinators and micro-organisms) is an important issue

(f) Development of resistance. Widespread use of GM crops could lead to the development of resistance in insect populations. Planting “refuge” areas with insect-susceptible varieties could reduce the risk of insect populations evolving resistance due to widespread cultivation of GMO Bt-crops.

Human health:

(a) Transfer of allergenic genes. These genes could be accidentally transferred to other species, causing dangerous reactions in people with allergies.

(b) Mixing of GMOs in the food chain. Unauthorised genetically modified (GM) products have appeared in the food chain. The GM maize variety Starlink, intended for animal feed, was accidentally used in human consumption products. Strict processing controls may be required to avoid future contamination.

(c) Transfer of antibiotic resistance. Genes that confer antibiotic resistance are used as “markers” in GMOs to indicate successful gene transfer. In view of concerns about the possibility of “marker genes” conferring resistance to antibiotics, this approach is being replaced with marker genes that avoid medical or environmental hazards, or removing marker gene following the process of identifying transgenics.

(d) Toxicity of products of transgenes. This is yet another concern.

Socio-economic:

(a) Loss of access to plant material. Biotechnology research is conducted mainly by the private sector. In the agricultural sector, there are concerns about market dominance by a few powerful companies, which could negatively impact small-scale farmers worldwide. The main fear concerns payment for patented crop varieties and seeds bred from genetic material that originated from farmers’ own fields. While the World Trade Organization’s Agreement on Trade-related Intellectual Property Rights (WTO/TRIPS) encourages this, there are options within the agreement to protect farmers’ traditional practices. Also, the International Treaty on Plant Genetic Resources for Food and Agriculture recognizes the contributions of farmers to the conservation and use of plant genetic resources over time and future generations. It provides for an international framework to regulate access to plant genetic resources and establishes a mechanism to share the benefits derived from their use. There are also concerns related to small farmer seeds being contaminated by proprietary Bt crops grown in adjoining fields, which have led to lawsuits of infringement by the biotech companies against small farmers

(b) Intellectual property rights may hinder research. The proprietary nature of biotechnology products and processes may prevent their access for public-sector research. This impact may be stronger in developing countries as they lack private research initiatives, and most do not provide patent protection to biotechnological products and technologies. As patents are national in scope, the entry of products developed through proprietary biotechnologies could be prevented in external markets where patent protection exists. On the other hand, Professor

Umaharan of the University of the West Indies (UWI) St. Augustine campus (2010, personal communication) believes that there is no hindrance to research, and the problem arises when the products are commercialised. Umaharan also notes that “it is difficult for small countries with adequate resources or human capacity to get approvals for each component of the technology used.”

(c) Impact of “terminator” technologies (Technology Protection System). These are under development and not yet commercialized. They could prevent a crop from being grown the following year from its own seed, thus preventing farmers from saving seeds for re-planting. This technology however has the potential advantage of preventing out-crossing of GM seeds.

Reynolds (1999) states that, “while biotechnological innovation is neither a panacea for agricultural ills nor a guarantor of successful sustainable agricultural practices, it provides many beneficial features.” Furthermore, the Food and Agriculture Organization (FAO) Statement on Biotechnology recognizes that genetic engineering could increase production and productivity in agriculture, forestry and fisheries, leading to higher yields on marginal lands in nations unable to grow sufficient food for their population. FAO is aware of concerns about potential risks posed by biotechnology. While new biotechnologies offer new opportunities for solving problems where traditional techniques have failed, the products of such technologies are usually developed for use by large-scale commercial interests. So far, small-scale farmers have not benefitted from the technology (FAO, 2003).

In agriculture, biotechnology is becoming the tool of necessity and choice (Reynolds, 1999; and today, GM products are present in over 80% of supermarket processed foods such as grains. Despite potential health threats, unless GM foods are shown to be substantially different from conventional foods, they are not differentiated by labelling in some countries. Furthermore, labelling is not mandatory in countries, for example, the United States and mixing GM crops with non-GM products confounds labelling attempts (Lendman, 2008; Stuart, 2009).

For various reasons, the acceptability of agricultural biotechnology (agrobiotech) foods varies among countries. In the United States, consumer sentiment towards GM foods is more favourable than in Europe and other countries, where they are more sceptical (Lesher, 2004). European criticism of agrobiotech products is reportedly based on socioeconomic and not food safety issues (Wambugu, 1999). As a result, a stringent regulatory regime for GM imports has been introduced in Europe. The difference in United States and European consumer attitudes possibly is related to different cultural values, cultural beliefs and experiences, and this may pose difficulties in sale of GM foods in Europe and other countries. Advertising may be unable to change such closely held consumer attitudes. Increased media coverage about GM products, even if positive, was shown to increase concerns. In recent surveys, consumers indicated a willingness to pay more for non GM alternatives (16-38% in the United States and up to 50% in Europe). These premiums are higher than the cost reductions associated with GM seeds. Many United States firms are responding to consumer interest in non GM products, and some have set limits on GM ingredients used in their products. These voluntary restrictions arose in order to sell in European and Asian markets, and from increasing pressure from advocacy groups. Segmented markets for genetically altered and conventional grains, however, may cause problems. A zero tolerance for GM content is estimated to raise soybean costs up to 50%, but a 1% tolerance might increase costs by 15% (Lesher, 2004).

The controversy of GMOs and intellectual property rights mainly relates to biopiracy-the foreign exploitation of natural resources.

3. Regulation of GMOs

In view of the concerns and controversies surrounding GMOs, several global multilateral agreements have been developed to regulate GMOs, including:

(a) Agreement on TRIPS

WTO/TRIPS came into effect on 01 January 1995 and is the most comprehensive multilateral agreement on intellectual property. It attempts to narrow the gaps in how rights are protected worldwide, and brings them under common international rules. It establishes minimum protection levels that each government has to give to the intellectual property of WTO members. It, therefore, strikes a balance between long-term benefits and possible short-term costs to society. In the long term, society benefits as intellectual property protection encourages creation and innovation. Governments can reduce short-term costs through various mechanisms. Furthermore, the WTO's dispute settlement system is available in the event of trade disputes over intellectual property rights. The agreement covers five broad issues:

(a) How basic principles of the trading system and other international intellectual property agreements should be applied

(b) How to give adequate protection to intellectual property rights

(c) How countries should enforce rights in their territories

(d) How to settle disputes on intellectual property between WTO members

(e) Special transitional arrangements during the introduction of the new system (www.wto.org/english/tratop_e/trips_e/trips_e.htm).

(b) Agreement on the application of Sanitary and Phytosanitary measures

The Agreement on the Application of Sanitary and Phytosanitary Measures (SPS) is an international treaty of the WTO, which entered into force in January 1995. The SPS Agreement relates to the application of food safety and animal and plant health regulations. It allows WTO members to set their own scientifically-based standards, to be applied only to the extent necessary to protect human, animal or plant life or health; and not arbitrarily or unjustifiably discriminate among members. For harmonization, members are encouraged to base their measures on existing international standards, guidelines and recommendations. Based on scientific justification or risk assessment, members may maintain or introduce measures that result in higher standards. The Agreement has 14 articles covering human, animal and plant health arising from international trade: harmonisation of standards; control, inspection and approval procedures; risk assessment; transparency; technical assistance; and dispute settlement. Prominent SPS cases involving GMOs are: the 2003 challenge by the United States against EU laws restricting the importation of GMOs, arguing they are "unjustifiable" and illegal under the SPS Agreement; and the 1996 challenge by the United States and Canada against EU directives prohibiting the import and sale of growth hormone-treated meat and meat products, alleging that they violated several provisions of the SPS Agreement (http://www.wto.org/english/docs_e/legal_e/); (http://en.wikipedia.org/wiki/Agreement_on_the_Application_of_Sanitary_and_Phytosanitary_Measures); (http://www.wto.org/english/tratop_e/spsund_e.htm)

(c) Agreement on Technical Barriers to Trade

The Agreement on Technical Barriers to Trade (TBT) is an international treaty of the WTO, which (in its present form) entered into force in January 1995. The TBT Agreement encourages the formal acceptance of standards among members through explicit agreements, thus ensuring that technical regulations/standards and testing/certification procedures do not create unnecessary obstacles to trade. The Agreement promotes the use of appropriate international standards, but does not require changes in protection level due to standardization. It mandates members to establish enquiry points and national notification authorities to answer queries on SPS regulations and notify other States of new regulations. It covers production methods related to product characteristics, conformity assessment procedures, notification provisions, and includes a Code of Good Practice for the preparation, adoption and application of standards by standardizing bodies (http://www.wto.org/english/doc_e/legal_e/ursum-e.htm#dAgreement).

(d) International Plant Protection Convention

The International Plant Protection Convention (IPPC) is an international agreement established in 1952 to protect cultivated and wild plants by preventing the introduction and spread of pests, while minimizing impacts on international trade. The Convention also covers research materials, biological control organisms, germplasm banks, containment facilities and anything acting as a vector for spread of plant pests. The IPPC plays an important role in international trade and biosecurity. It allows States to analyse risks to national plant resources and use science-based measures to safeguard plants. It focuses on: developing International Standards for Phytosanitary Measures (ISPMs) to safeguard plant resources; information sharing; and capacity building for implementing the IPPC and related international phytosanitary standards. The ISPMs specific to Living Modified Organisms (LMOs) are: “Framework for pest risk analysis” and “Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms.” The former describes the pest risk analysis (PRA) process within the scope of the IPPC, introduces the PRA stages (initiation, pest risk assessment, and pest management), and outlines procedures for determining the pest potential of living modified plants. The other standard details the conduct of PRA to determine if pests are quarantine pests. It describes the integrated process for risk assessment and selection of risk management options, and provides guidance on evaluating potential phytosanitary risks to plants and plant products by LMOs. Annex 2 to this standard provides explanatory comments on scope of the IPPC in regard to PRA for LMOs, and Annex 3 focuses on determining the pest potential for a LMO. Phytosanitary measures that conform to the ISPMs are presumed to be consistent with relevant provisions of the SPS Agreement; and IPPC dispute settlement procedures, while non-binding, can substantially influence WTO disputes raised under the SPS Agreement (FAO, 2009a; https://www.ippc.int/).

(e) World Organization for Animal Health

The Office International des Epizooties (OIE) was created, through the international agreement signed on 25 January 1924, to fight animal diseases at the global level. Although the Office became the World Organization for Animal Health in May 2003, its historic acronym was kept. The OIE is an intergovernmental organization, with the mission to: ensure transparency in the global animal disease situation; collect, analyse and disseminate veterinary scientific information; provide expertise and encourage international solidarity in the control of animal diseases; safeguard world trade by publishing health standards for international trade in animals and animal products; and improve the legal framework and resources of national Veterinary Services. Since its creation, the OIE has played a key role in its capacity as the sole international reference organization for animal health. OIE standards are contained in its Terrestrial Animal Health Code, Aquatic Animal Health Code and publications on Diagnostic Tests and Vaccines. GMOs are addressed specifically under sections “Somatic cell nuclear transfer-SCNT in production livestock and horses” and “Collection of processing of micromanipulated embryos/oocytes from livestock and horses” of the Terrestrial Animal Health Code 2010. Recommendations are restricted to SCNT, and based on a risk analysis/approach to biotechnology-derived animals categorised according to life-cycle: embryos, recipients, offspring and progeny of animal clones. The recommendations address animal health aspects of production animals derived from reproductive biotechnologies (http://www.oie.int/eng/oie/en_oie.htm).

(f) Codex Alimentarius Commission

The Codex Alimentarius Commission (CAC) was created by FAO and the World Health Organization (WHO) to develop food standards, guidelines and related texts under the Joint FAO/WHO Food Standards Programme. The programme aims to protect consumer health and ensure fair trade practices in the food trade, and promote coordination of all food standards work by international governmental and non-governmental organizations. Codex has adopted principles and guidelines to assess safety of foods derived from GM plants, animals and microorganisms. A government that chooses to build a regulatory mechanism to address food safety of GM-foods can use Codex text as a basis. A government is free to adopt its own policy regarding use of GMOs in agriculture and other sectors. The CAC is recognized by WTO as an international reference point for resolution of disputes concerning food safety and consumer protection (www.codexalimentarius.net/web/index_en.jsp).

(g) Cartagena Protocol on Biosafety

The Cartagena Protocol on Biosafety to the Convention on Biological Diversity is an international agreement that aims to ensure safe handling, transport and use of LMOs derived from modern biotechnology that may have adverse effects on biological diversity and risks to human health. It was adopted on 29 January 2000 and entered into force on 11 September 2003. It establishes an advance informed agreement procedure to ensure that countries are provided with relevant information to make informed decisions before importation of such organisms. The protocol refers to a precautionary approach and reaffirms the precaution language in Principle 15 of the Rio Declaration on Environment and Development. The Protocol establishes a Biosafety Clearing-House for exchange of information on LMOs and for assisting countries in implementation of the Protocol (www.cbd.int/biosafety).

(h) International Treaty on Plant Genetic Resources for Food and Agriculture

The International Treaty on Plant Genetic Resources for Food and Agriculture is crucial in the battle against hunger and poverty, and essential for achieving Millennium Development Goals 1 (end poverty and hunger) and 7 (environmental sustainability). International cooperation and open exchange of genetic resources are necessary for food security as no single country is self-sufficient in plant genetic resources and countries depend on each other for genetic diversity in crops. The fair sharing of benefits arising from use of these resources has, for the first time, been implemented internationally through the Treaty and its Standard Material Transfer agreement. The goals of the Treaty are to:

(a) Recognize farmers' contributions to the diversity of crops that feed the world

(b) Establish a global system to provide farmers, breeders and scientists with access to plant genetic materials

(c) Ensure recipients share the benefits derived from use of genetic materials with countries from where they originated (www.planttreaty.org/textx_en.htm).

B. INDUSTRIAL BIOTECHNOLOGY

In industrial biotechnology, modern molecular biology techniques, using micro-organisms, enzymes and their products, are applied to improve energy efficiency and reduce environmental impacts of industrial processes such as textile, paper and pulp, and chemical manufacturing. For example, protease is substituted for cleaning compounds in detergents, and its production results in a biomass that yields organic fertilizer. In the textile industry, biotechnology produces biotech-derived (Bt) cotton with superior characteristics in terms of warmth, strength, improved dye uptake and retention, and absorbency. Crops can replace petroleum in chemical production, by fermenting its sugar to acid, which is used to produce feedstock for other products (ECLAC, 2008a). At present, three biofuels account for nearly all consumption in the global transport sector: bioethanol produced by fermentation of sugarcane, sweet sorghum, sugar beet, maize, barley, wheat and cassava; biodiesel produced from oilseed crops, used cooking oils and animal fats; and biogas produced from energy crops and organic wastes. In general, biofuels may be useful in reducing greenhouse gas (GHG) emissions and increasing energy security by providing an alternative to fossil fuels (ECLAC, 2007a). It is projected that by the first half of the next century, 30% of global chemical and fuel needs could be supplied by renewable resources (ECLAC, 2008b). In the wood pulping industry, biopulping reduces electrical energy requirements by 30%. Biocatalysts, such as enzymes, are developed and manufactured in commercial quantities, and biomedical applications of enzyme technology include: synthesis of new anti-microbial compounds; enzyme replacement therapy; cancer treatment; enzyme graft and dermatological applications; enzyme activators of precursor biomolecules; and dentistry. Novel applications and future uses of enzyme technology (ECLAC, 2008a) include:

(a) Exploitation of enzymes as electro catalysts

(b) Enzymes as analytical tools to measure specific compounds

(c) Enzymes in the synthesis of bulk organic materials and production of fragrances and cosmetics

(d) Enzymes in formation of food flavours and aroma compounds

(e) Enzymes as tools for detoxification of pesticide residues

(f) Enzymes as monitors of toxic chemical levels in food and water

In spite of the benefits of industrial technology, there are obstacles to its development. Screening for new enzymes is costly, so the intellectual property generated must be protected, usually by patenting the enzyme, production method or use. Despite the value of biofuels and the contribution to addressing the negative climate change impacts, concerns have arisen: the nitrous oxide released contributes more to global warming than fossil fuels; impractical long-term solution to transport fuel needs; low biofuel conversion efficiency (using crop or agricultural wastes); utilization of crops for food or fuel; negative impacts on food sovereignty, rural livelihoods, forests and other ecosystems (ECLAC, 2007a). The opportunities and risks of using bioenergy for food security in Latin America have been discussed (CEPAL, 2007). The perspectives of, and existing constraints on development of modern industrial biotechnology are mainly in industrialized nations while the performance of Caribbean countries remain marginal (ECLAC, 2008a).

C. ENVIRONMENTAL BIOTECHNOLOGY

The International Society of Environmental Biotechnology defines environmental biotechnology as "the development, use and regulation of biological systems for remediation of contaminated environments (air, land, water), and for environment-friendly processes (green manufacturing technologies and sustainable development)."

Environmental biotechnology has applications in waste treatment and pollution prevention. Compared with conventional methods, these applications can more efficiently clean many wastes and significantly reduce dependence on land-based disposal methods. The broadest application of environmental biotechnology is bioremediation, using bacteria to transform waste into harmless by-products. It is an area of increasing interest. Enzyme reactors have been developed to pre-treat waste components (industrial and food), facilitating their removal through the sewage rather than solid waste disposal systems. Waste can be converted to biofuel, and microbes induced to produce enzymes to convert plant materials into building blocks for biodegradable plastics. The by-products of micro-organisms in bioremediation can be useful. For example, methane produced by bacterial degradation of sulphur liquor, a waste product of paper manufacturing, can be used as a fuel (ECLAC, 2008a).

Some of the risks associated with agricultural and industrial biotechnology, identified in the previous sections of this report, also apply to environmental biotechnology.

D. MEDICAL BIOTECHNOLOGY

This section presents examples of how biotechnology products may be applied in medicine and forensics: Pharmaceuticals, Medical diagnostics and DNA fingerprinting (ECLAC, 2008a).

The cloning of human genes in *Escherichia coli* or yeast has enabled production of unlimited quantities of human proteins *in vitro*, for the first time. The cultured cells are used to manufacture over 100 products for human therapy, such as insulin for diabetics. Similarly, animal growth hormones are produced by the fermentation of transgenic bacteria that have received the selected human, cow or pig gene (ECLAC, 2008a).

Medical diagnostic applications include gene therapy; diagnosis of infectious diseases and genetic disorders; harnessing microbes for health; and forensics. The first clinical gene therapy is underway to correct the enzyme deficiency Adenosine Deaminase Deficiency in children. The process involves removal of bone marrow cells, supplementing defective DNA in the cells with a copy of normal DNA, and returning the repaired cells to the patient. Gene therapy is a technique to correct defective genes associated with disease development. Approaches to correct faulty genes are: most commonly a normal gene is inserted into a nonspecific location within the genome to replace an abnormal one; an abnormal gene is swapped for a normal one through homologous recombination; the abnormal gene is repaired by selective reverse mutation; and alteration of regulation of a particular gene (http://www.ornl.gov/sci/techresources/Human_Genome/medicine/genetherapy.shtml). Due to the risks associated with experimental gene therapy, the technique is currently only being tested for treatment of non-curable diseases (http://ghr.nlm.nih.gov/handbook/therapy/genetherapy).

Diagnosis of infectious diseases is a profound application of DNA technology. Many infectious diseases such as tuberculosis and AIDS, and some inherited disorders such as cystic fibrosis and sickle cell anaemia, are diagnosed within hours by the Polymerase Chain Reaction (PCR) technique. The greatly increased sensitivity and speed of the PCR technique over traditional methods enable earlier intervention and treatment. PCR will be soon available to diagnose crop and livestock diseases. Harnessing microbes for health has applications in the development of large-scale microbial-based sewage purification systems to control major disease outbreaks in overcrowded industrial cities; and the large-scale production of antibiotic penicillin (ECLAC, 2008a).

DNA fingerprinting and PCR techniques are used to diagnose viral, bacterial or fungal infections; determine family relationships; and map gene locations on DNA. In forensics, DNA fingerprinting is becoming common practice. Immunoassays are used for testing drug level and pregnancy; detection of levels of pesticides, herbicides, and toxins in crops and animal products; and industrial chemicals in groundwater, sediment and soil. DNA fingerprints are generated using RFLP to determine family relationships, match organ donors with recipients, connect crime suspects with DNA evidence, or serve as a pedigree for seed or livestock breeds. Genetic “maps,” used to locate genes, are generated by statistical analyzes, PCR, RFLP, and DNA sequencing. Maps are developed for humans, and various plants and animals with commercial or research importance (ECLAC, 2008a).

Sasson (2005) examines some of the most controversial areas of medical biotechnology, including stem cell research and gene therapy and some associated ethical issues. Gene therapy faces many obstacles before it can become a practical approach for treating diseases. These include: gene delivery tools (viruses), high costs, limited knowledge of gene functions, and multigene disorders and effect of the environment. Issues with genetic testing include: discrimination in employment or insurance, designed babies, foetal abortions, human and animal cloning, effects on social institutions (www.elsi/legislat.html ORNL.org).

IV. BIOTECHNOLOGY DEVELOPMENT IN THE CARIBBEAN: APPLICATIONS, OPPORTUNITIES AND RISKS

Contemporary research in Asia, Latin America and Africa has led to widespread use of tissue culture and genetic engineering in maintaining export markets and creating new ones. Although current efforts in the Caribbean indicate a growing trend, the region is already behind, and biotechnology is still regarded as a fledgling industry. Caribbean biotechnology focuses mainly on application of fermentation and enzyme technologies, tissue culture and rDNA technology. Of these, plant tissue culture is most developed, but rDNA technology is becoming increasingly important in agriculture. At the national level, Cuba from the 1990s has placed special emphasis on biotechnology applications to increase agricultural productivity and develop aquaculture (ECLAC, 2008a,b). As in Africa (Wambugu), Caribbean biotechnology is needs-based. The application of biotechnologies in the region is described in the following text.

A. INDUSTRIAL BIOTECHNOLOGY

1. Fermentation technology

In the Caribbean, there is limited application of fermentation technology to generate industrial products, with Cuba and Puerto Rico making the most use of this technology. The most common application in the Caribbean has been the fermentation of rum and beer. Moreover in the sugar industry, research has focused on use of products and by-products to generate value-added products, which can decrease foreign exchange expenditure through import substitution and increase revenue from non-traditional exports. A novel process of production of xanthum gum from molasses, for use in the pharmaceutical and chemical industries, has been developed and patented (ECLAC, 2008a,b)

Regional biomethanation programmes have been supported by the Caribbean Development Bank. Jamaica, with OLADE funding, has been experimenting with various biodigester designs and models. Other applications of fermentation technology (ECLAC, 2008a,b) include:

(a) Fermentation of sorghum for food and feed

(b) Uses of waster yeast from the fermentation industry

(c) Identification and characterization of local food pathogens to increase regional food safety

(d) Production of citric acid from molasses

(e) Use of beneficial fungus, *Vescicular arbuscular mycorrhyzae* to increase vegetable/legume crop yield in red kidney beans (*Phaseolus vulgaris*), winged bean (*Psophocarpus tetragonolobus*), and moth bean (*Vigna aconitifolia*)

(f) Development of legume inoculant

(g) Recycle agriculture wastes to produce animal feed and organic fertilizer

(h) Substitution of antibiotics with microbes in animal feed

Caribbean countries have the potential to produce bioethanol from sugar cane, which is the most efficient plant in terms of biomass production. To date, countries that have indicated an interest in bioethanol production or use include: Cuba, Jamaica, Guyana and the Dominican Republic. The latter has also indicated an interest in biodiesel production (ECLAC, 2007b).

2. Enzyme technology

Investigations are being conducted at UWI on the properties and activities of enzymes (ECLAC, 2008a).

B. AGRICULTURAL BIOTECHNOLOGY

1. Tissue culture

Most tissue culture work on crops was initiated at the UWI St. Augustine Campus in the early 1980s. Protocols have been developed for several tropical plants, such as banana, plantain, pineapple, aloe, breadfruit, jackfruit, sweet potato, cocoa, anthuriums, orchids and carambola. An *in vitro* breeding method for *Fusarium* resistance in banana was developed as well as an *in vitro* hardening method for banana. At the Caribbean Agricultural Research and Development Institute (CARDI), which has led the region's development of agricultural biotechnology since 1975, protocols for producing yam varieties free from brown spot virus were developed, as well as germplasm storage and commercial micropropagation of anthurium. More recently, tissue culture has been used as an economical tool for the micropropagation of many food and ornamental plants, and examples in the Caribbean agricultural sector (ECLAC, 2008a,b) include:

(a) Support for bulk production of citrus fruits and root crops, and conservation and production of native orchids and floristic ornamentals in the Bahamas

(b) Since 1979 in Barbados, the White Lisbon cultivar of yam *Discorea alata* has been improved by eliminating the internal brown spot viral disease. Distribution of improved plants led to a 40% yield increase. Also, resistant strains of hot pepper and tomato to bacterial spot disease have been developed

(c) In Dominica, the leaf burning disease in cocoyam (tannia) caused by a fungus *Pythium myriotylum* has been eliminated by biocontrol systems

(d) The spread of moko disease in bananas caused by bacteria *Pseudomonas solanacearium* in Grenada has been controlled

(e) The National Agricultural Research Institute and FAO are producing shoots from dormant axillary buds of pineapple (*Ananas comosus*) in Guyana

(f) Jamaican applications include: development of virus-free plant material for Irish potato *Solanum tuberosum*; production of plants for yam varieties *Dioscorea cayensis*, *D. rotunda*, *D. alata and D. trifida*; development of the mushroom industry with oyster mushrooms *Pleurotus sajor-caju*; development of strains of the hot pepper *Caspcium chinense* resistant to potyviruses; and development of tissue protocols for sweet potato *Ipomoea batatas*, cassava *Manihot esculenta*, dasheen *Colocasiaesculenta*, plantains *Musa* spp., breadfruit *Artocarpus altilis*, jackfruit *A. heterophyllus*, carambola *Avevrhoa carambola*, yam bean *Pachyrhizus erosus*, cacao *Theobroma cacao*, pineapple *Ananas comosus*, and sugar cane *Saccharum officinarum*

(g) Tissue culture is used for production of tuber crops in St. Kitts and Nevis

(h) Yam cultures were introduced in St. Vincent and the Grenadines

(i) In Trinidad and Tobago, UWI is developing protocols and biocontrol and quarantine measures for improving yields of yams, sweet potatoes, cassava, and plantains.

(j) The Caribbean Agriculture Research and Development Institute (CARDI) is the repository for virus-free yam material and germplasm storage of selected crop species of economic significance

(k) At the UWI Mona campus, extracts from some plants were identified as having potential in medicine: unripe tamarind (antibacterial activity), leaf-of- life leaves *Bryophyllum pinnatum* (antibacterial activity), spirit weed *Eryngium foetidium* (anti-convulsion properties), breadfruit *Artocarpus altilis* (anti-inflammatory potential), freeze-dried noni *Morinda citrifolia* (anti-inflammatory potential), choline-rich plant *Abutilon trisulcatum* (treatment of memory disorders), ginger *Zingiber officinale* (treatment of rheumatoid arthritis), neem (disinfectant potential), microbes in animal feed (antibiotics), Guinea hen weed (bioactive anti-cancer), turmeric *Curcuma longa* (anti-inflammatory), aloe *Aloe vera* (enhances immune function), and sarsaparilla *Smilax regelii* (prevents/relieves rheumatism).

Research is being conducted on methods for food preservation and extension of shelf-life of plant products. UWI Mona and St. Augustine campuses are involved in joint ventures in tissue culture applications. Also, the Jamaican Government has been collaborating with industry to produce white potatoes, ginger, banana and yam. In Trinidad and Tobago, gingerlilies, roses and orchids are produced for local markets. Recently, embryo transfer has been used to boost meat and milk production in the region (ECLAC, 2008a).

2. Recombinant DNA technology

The rDNA technology, developed at UWI St. Augustine campus, has been applied successfully in the anthurium industry. This commercial venture aims to increase the colours of anthurium *Anthurium andraeanum*, by introducing genes from other species that code for new colours, thus enhancing marketability. Development of disease- and pest-resistant varieties are being investigated (ECLAC, 2008a,b; 2009a).

At UWI Mona campus, varieties of papaya resistant to ring spot disease are being developed using transfer of resistant genes from local varieties (ECLAC, 2008a; 2009a). Results indicate up to 80% transgenic plants are virus-free, and research continues to ensure 100% success. These techniques are used also to produce virus-resistant orange and grapefruit varieties. Research is being conducted on somatic clonal variations of guinea henweed and ackee (ECLAC, 2009a,b).

3. Molecular markers

RFLPs and RAPDs have been used to determine stock structure of the four-wing flyingfish, *Hirundichthys affinis*, in the central western Atlantic for management purposes. Research indicated that the Caribbean stock is genetically separate from the South American stock and should be managed separately. Microsatellite markers have been used to determine Barbados Blackbelly sheep population structure and examine genetic diversity of this population compared with other populations (West African, Virgin Island White, and United States). Results showed both phenotypic and genotypic differences between Barbados and United States Blackbelly populations. Cocoa genetic resources at the International Cocoa Genebank in Trinidad have been fingerprinted using multiplex SSR molecular markers and SNP markers, and this has allowed for identification of mislabelled accessions. The information has also been used to develop a core collection representing the cocoa genepool with desirable characteristics (ECLAC, 2008a,b).

Specific to crop improvement, molecular markers have been used to identify heterotic groups within hot pepper *Capsicum chinense*. AFLP techniques have been used to identify markers for sugar and fibre content in sugarcane, to improve yield. SSR markers associated with disease resistance, butterfat content and other important traits in cocoa (*Theobroma cacao*) is being developed using association mapping. In anthurium, molecular markers linked to bacterial blight resistance are being investigated in collaboration with researchers in the United States (ECLAC, 2008a).

With respect to diagnostics, the Dominican Republic, Trinidad and Tobago, France and the United Kingdom are involved in the EU-funded regional project, BETOCARIB, which aims to develop molecular markers to characterize begomoviruses and strains affecting tomato plants in the Caribbean (ECLAC, 2008a) and identification of tomato varieties resistant to the various strains.

There is ongoing work to characterize bacterial strains in the family Solonaceae and Musaceae (*Ralstonia solanacearum*), pepper viruses, coconut diseases, tristeza virus in citrus, and bacterial and fungal diseases in vegetables. The improved precision in pathogen diagnosis is facilitating development of appropriate quarantine measures by the Council for Trade and Economic Development and providing a tool for epidemiological studies on integrated pest management (ECLAC, 2008a).

C. MEDICAL BIOTECHNOLOGY

Since the early 1980s, Cuba has invested in red (medical) biotechnology and is an important producer of biotechnology-derived medicines, vaccines and diagnostic kits. The foreign exchange from sale of these products is an important contributor to Cuba's GDP (ECLAC, 2008a).

D. CLIMATE CHANGE

Climate change is a major challenge in this century and increasingly, biotechnology is seen as providing solutions to address the impacts. Economic and social impacts of climate change and accompanying adaptation and mitigation costs are documented in the Stern Review. The Caribbean region needs to examine how biotechnology could address the challenges posed by these impacts and thereby make the region more competitive globally and more resilient to external threats (natural and economic). Biotechnology is seen as an effective tool to combat climate change by development of new, high-yielding, disease-resistant and climate-adaptive crops to compensate for decline in food production. To achieve this requires substantial effort and investment in research and development (R&D), and support from government and private sector within agreed policy frameworks. In this regard, UWI has stated its commitment to research in this area. It has emphasized the importance of a scientific approach, which is important in alleviating or minimizing climate change impacts, and technology (particularly biotechnology), which can support this objective from a regulatory and policy perspective. It is noted that although plant varieties could be developed through genetic engineering, to better adapt to climate change, transformation could result in other less desirable impacts. At a regional level, funding for such R&D could be made available by the Inter-American Institute for Cooperation on Agriculture (ECLAC, 2009a,b), and internationally the International Treaty on Plant Genetic Resources for Food and Agriculture (the Treaty) will invest more than US$ 10 million through its 2010 call for project proposals. The call will help to ensure sustainable food security and to assist farmers to stay ahead of the climate change curve. The call gives the opportunity to any governmental or nongovernmental organization, including genebanks and research institutions, farmers and farmers' organizations and regional and international organizations based in one of the 89 eligible member countries to apply for grants. The role of the Treaty as a central instrument for climate change adaptation has received wide support from environment officials and international experts from over 30 countries (www.planttreaty.org/rss/rssnews_en.asp).

E. CONSTRAINTS TO BIOTECHNOLOGY DEVELOPMENT

Agenda 21, the work programme adopted by the United Conference on Environment and Development in 1992, asserted that biotechnology "promises to make a significant contribution in enabling the development of, for example, better health care, enhanced food security through sustainable agricultural practices, improved supplies of potable water, more efficient industrial development processes for transforming raw materials, support for sustainable methods of afforestation and detoxification of hazardous wastes." Subsequent to the adoption of these commitments, little progress in the application of biotechnology in the developing world is evident despite visions of a promising future (ECLAC, 2008a).

Biotechnology is becoming increasingly important in the Caribbean. At UWI, biotechnology application and its role in human development is one of its research pillars and a Biotechnology Centre has been established at its Mona campus. The Dominican Republic established its Biotechnology and Biodiversity Centre in 2000 as the national and scientific base for sourcing biotechnology solutions for problems affecting agriculture, forestry and fisheries. The Centre is the base for exploiting modern biotechnologies using specialized laboratories focusing on tissue culture, molecular biology, molecular diagnostics, germplasm management, industrial biotechnology and neutraceuticals. The Centre provides training at the Masters level, and protocols have been developed for a variety of biotechnology products (biopesticides, medicinal extracts, diagnostic methods) (ECLAC, 2008a). The Trinidad and Tobago government has indicated its commitment to establish a TT$7 million fund for the creation of a biotechnology centre at the University of Trinidad and Tobago (ECLAC, 2009a,b).

The Caribbean region has maintained a positive attitude towards biotechnology although there has been a general absence of innovation in industry. The focus has been on agrobiotech, and the performance of Caribbean countries in industrial technology remains marginal. CARICOM countries lack comprehensive legal or regulatory frameworks to address the major issues relevant to biotechnology. Existing legal and administrative mechanisms within the region are not adequately designed to address modern biotechnology issues such as R&D, trade, biosafety, food safety and labelling. In this regard, CARICOM in 2003 mandated CARDI to develop a regional policy on biotechnology and biosafety, and endorsed the support of commercialization of biotechnology in the Caribbean region in 2005, and is now formulating a regional biotechnology policy/strategy covering: innovation and technology, regional priorities, institutional framework, information sharing, public awareness, and new economic models for biotechnological research. The National Biosafety/Biotechnology Committee in Grenada was set up to deal with issues related to the Cartagena Protocol on Biosafety, and Grenada has developed legal instruments relevant to GM food imports. Barbados also has established a National Biosafety/Biotechnology Committee; and regionally, a Caribbean Biotechnology Network has been established. Despite these initiatives and owing to lack of regulatory frameworks concerning modern biotechnology, no biotechnology products currently are approved for direct consumption, processing or animal feed. Moreover, there is lack of information on field testing of biotechnology crops, and the region's policy on co-existence of biotechnology and non-biotechnology crops. Meanwhile biotechnological research continues at academic institutions, and (faced with the challenges of globalization) several Caribbean islands have embarked on self-reliant strategies for national and regional development, including the potential of biotechnology for growth and development (ECLAC, 2008a; 2009b).

Biotechnology development is critical to achieving the region's development goals and to function in an increasingly competitive global economy. In the Caribbean, greater biotechnology application could benefit from development of a regional policy and strategy, and expansion and improvement of institutions, public-private partnerships, resource provision structure, venture capital, multi-disciplinary highly skilled teams, public awareness and appropriate communication strategies (ECLAC, 2008a,b). Details of recommendations for development of biotechnology in the Caribbean are provided in ECLAC (2008a).

V. APPLICABILITY OF BIOTECHNOLOGY TO THE CARIBBEAN: DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

From the information presented in the previous section of this report, it is noted that biotechnology development and application in the Caribbean region, has focused on agricultural biotechnology (mainly tissue culture and to a lesser extent on rDNA technology). Agricultural biotechnology however has developed in a limited and uneven way in the Caribbean (ECLAC, 2008a). Developments in industrial biotechnology (mainly fermentation technology), environmental and medical biotechnology have trailed agrobiotech developments, with the latter two being limited in the region. The development and application of blue or marine biotechnology in the region is almost non-existent. There exists therefore the potential for developing other biotechnologies apart from agrobiotech, which should be explored by Caribbean nations. Biotechnology also has potential applications to climate change, the single most important issue confronting mankind today.

While biotechnology holds great promise for developing countries, this promise cannot be realised unless capability is built into the supporting processes. Few developing countries have the R&D infrastructure to undertake biotechnology research as they lack trained scientific personnel and well-equipped laboratories. Even fewer have the industrial capability to develop and exploit research results. International agencies thus have a critical role to play in providing technical assistance and catalyzing joint R&D efforts between laboratories and firms in developed and developing countries. Developed countries gain access to raw material and retain marketing rights; and the developing country gains expertise, financial backing and regional marketing rights. Adapting innovation and making structural changes pose unique challenges for the developing world. For example, public and private investment in agriculture and agricultural R&D is critical to adapting new biotech practices; but limitations in a country’s political, social, and economic structures may challenge its ability to adopt and support increased agricultural biotechnology successfully. This is true for countries with a weak agricultural science base and poorly developed academic and market infrastructures (Zilinskas & Lundin, 1993; Reynolds, 1999). The technological gap between developed and developing countries is regarded as the most important constraint to biotechnology development in the developing countries, and it is continuously widening, as new biotechnologies are being developed rapidly (ECLAC, 2008a).

Despite these challenges, some developing countries (Brazil, China, Cuba, Egypt, India, South Africa and South Korea) have been able to develop successful health biotechnology sectors (Thorsteindottir *et al*., 2004). The key factors for establishment of a successful health biotechnology sector are: focus on local health needs; recognize the different ways of expressing success; and build on educational and health systems. The main lessons on promoting health biotechnology in developing countries are: strong political will, individual leadership or ‘champions,’ niche areas, close linkages and active knowledge flows, enterprise creation, and patent legislation. Cuba’s success with limited financial resources is based on: ensuring long-term governmental vision and policy coherence; promoting domestic integration to spur innovation; capitalizing on international linkages; and tapping into national pride. Cuba’s success also resulted from: the United States trade embargo, which forced Cuba to develop local health solutions (successfully developed the world’s first and only meningitis B vaccine); revision of its foreign investment laws; collaboration and resource-sharing among different institutions in its innovation system; and cluster development (West Havana Scientific Pole). Cuban commercial entities are selling health products to several countries and have agreements with foreign firms to develop and market Cuban vaccines. These lessons are critical for fostering development of a successful health biotechnology sector; and provide a strong message that developing States can successfully build capacity in health biotechnology to: increase availability of health products for their populations and provide opportunities for economic development. The case studies provide examples for reference by other developing countries and also by policymakers in international donor organizations and bilateral aid agencies, and the business and scientific communities in developed and developing countries. Developing countries can harness the potential of health biotechnology to improve the health of their populations. To fully realize the potential benefits however, will require concerted and sustained effort and ingenuity over many years.

As a result of the global importance of climate change, biotechnology increasingly is seen as providing solutions to address the impacts. In view of this importance, global funding to address climate change has increased drastically, and the Caribbean should take advantage of this opportunity to address regional climate change concerns. Agrobiotech potentially can provide new, high-yielding, disease-resistant and climate-adaptive crops to compensate for predicted decline in food production. Agriculture accounts for approximately 14% of GHG emissions, and annual GHG emissions from agriculture are set to increase in the future. As agricultural land can store and sequester carbon, farmers particularly in poor countries, should be involved in carbon sequestration to mitigate climate change impacts. Sustainable use of genetic diversity and carbon sequestration are among several options farmers can apply to mitigate GHG emissions in agriculture. Carbon markets that provide strong incentives for carbon funds in developed nations to purchase agriculture emission reductions from developing countries could provide investments for rural development and sustainable agriculture in developing countries (FAO, 2009b).

Latin America and the Caribbean still have huge potential for increasing arable land, which partly could be used for bioenergy crops. If guided by well-crafted policies and programmes, the crops could benefit small farmers without endangering the region's forests or food security (CEPAL, 2007). Biofuels have the potential to reduce GHGs, which contribute to climate change. While biofuels are not a total solution to the global energy problem, they potentially can develop cleaner energy and contribute to reducing climate change. It is important that countries consider the total impact of a growing biofuel industry on their economies, including economic resilience, job generation, rural-urban drift and support for local agriculture. Recommendations to optimize yields and productivity of biofuels are provided in ECLAC (2007a): control of fertilizer prices; efficient water collection and management; strategies for managing crop residues; partnerships between developed and developing countries; certification standards; public sector management and support; legislation; integrated agro-energy farming policies; and government support for research. For developing countries, the challenge is in finding resources for large-scale biofuel production by buying into the best technology and processes available.

More general recommendations to guide the application of biotechnology to climate change in the Caribbean (ECLAC, 2009a) include:

(a) Tertiary institutions should integrate their research agendas to improve R&D in biotechnology

(b) The linkages between science and policy should be created by convening meetings to share research findings and discuss appropriate policies

(c) Allocation of financial resources would be critical to development of a research agenda in support of policy development

(d) Time and financial resources should be invested in identifying any negative feedback and providing solutions

(e) Provide the necessary facilities, finances and expertise to encourage researchers to focus their research on policy development and change

(f) Devise a mechanism to move the document from draft to adoption of policy

(g) Science should inform policy. Thus, devise a mechanism for keeping policymakers abreast of scientific developments.

The industrial biotechnology is still in its infancy, yet globally it avoids the creation of 33 million tonnes of carbon dioxide each year through various applications (excluding ethanol use) whilst globally emitting 2 million tonnes of carbon dioxide. The full climate change mitigation potential of industrial biotechnology ranges from 1 billion to 2.5 billion tCo_2e per year by 2030, compared with a scenario where no industrial biotechnology applications are available. To determine to what extent industrial biotechnology can transform a fundamentally unsustainable system into a sustainable biobased economy, four fundamental dimensions of the industrial biotechnology contribution have been identified. These are: improved efficiency; substitution of fossil fuels; substitution of oil-based materials; and creation of a closed loop system to potentially eliminate waste. As the industry matures, the elimination of oil based products and closed loop systems could possibly comprise the major proportion of the industry's GHG reduction contribution. There are significant differences between the reduction potential of the four dimensions, and also the extent of high and low-carbon feedbacks they create. The actual impact of industrial biotechnology on GHG emissions will largely depend upon the socio-economic environment and the policy associated with the technologies. Therefore, for industrial biotechnologies to realize their full GHG emission reduction potential, strong public policies and private sector strategies need to be in place to channel the sector's growth toward low-carbon paths, while avoiding high carbon lock-ins. Such policies and strategies should: support existing and new efficiency-enabling solutions to fully capitalize on their short-term potential; anticipate and nurture progression towards large-scale biomaterial and closed loop systems; and ensure sustainable management of the supply of industrial biotechnology feedstock land. These goals can be realized with strategies (Kornerup Bang *et al*., 2009) such as:

(a) Scoping markets to identify areas to achieve higher GHG emission reductions with existing or emerging industrial biotechnology applications

(b) Developing standards and tools to document the GHG impacts of industrial biotechnology solutions

(c) Developing funding instruments for low-carbon solutions

(d) Pursuing R&D and market investments in biobased materials, including solutions to 'close the loop'

(e) Developing policies to support large scale biomaterial and closed loop systems

(f) Supporting development and implementation of policies to address the risk of unsustainable land-use practices being linked with industrial biotechnology feedstock production.

Marine biotechnology applications are limited in the Caribbean despite the importance of the Caribbean Sea and its marine resources to the region. The high biodiversity in tropical seas represents the world's most abundant, but least utilized, living resources. Marine biotechnology, "the application of scientific and engineering principles to the processing of materials by marine biological agents to provide goods and services," has many applications potentially important to developing nations: aquaculture, natural products chemistry, cell culture, bioremediation, bioadhesion, biosensors, and public health (Zilinskas & Lundin, 1993).

There has been a marked increase in the development of clean technologies in the industrial world, but Caribbean countries neither possess nor could easily access the advanced technologies for effective use of their resources. Obstacles that hinder the transfer of clean technologies from developed countries to developing ones are: lack of adaptation to local conditions; inadequate scientific and technological background; reluctance of industrial firms to release state-of-the-art technologies; and lack of funds in developing States. Also, policy inadequacies and the slow pace of economic growth and investment in the Caribbean have further hindered the adoption of cleaner solutions. Within the next two decades, energy consumption by developing countries will increase by nearly double, and significant investment will be required to expand existing energy systems and technologies. Several regional initiatives in agriculture, mining and tourism have resulted in use of cleaner technologies mainly in renewable energy and waste management. In waste management, the most critical need is for hazardous waste management as most islands lack such technology. Measures to promote wider adoption of cleaner technologies include: greater regional collaboration; institution of incentives, regulatory mechanisms and standards; public debate and information dissemination; and aid from advanced countries. The challenge is to find ways of achieving greater use of cleaner technologies that would lead to sustainable development in the region (UNEP, 1999).

According to ECLAC (2010a), Caribbean SIDS must bridge a significant science and technology to modernize production and institutional structures for self-sustaining growth and development. Caribbean STI has been directly linked to the decline of traditional sectors (agriculture and minerals) and hampered efforts to diversify into new high value-added activities. It is, however, recognised that development of STI can lead to an increased economic growth and resilience, through: commercialization of products and intellectual property; improvement in safety and health; ensuring food and energy security; and reducing environmental impacts.

Base on the foregoing, there is an urgent need for development and use of biotechnology in the Caribbean region, especially in non-agrobiotech sectors, to address food security, climate change, poverty, environmental degradation, among other issues. In so doing, countries must take advantage of the opportunities presented by biotechnology to gain competitive advantage and benefits for their populations, while at the same time put measures in place to reduce or remove the associated risks. Countries must ensure that economic as well as social and cultural issues are properly considered and balanced.

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