AgBioForum, 7(1&2): 13-22. ©2004 AgBioForum.

Agricultural Applications of Biotechnology and the Potential for Biodiversity Valorization in Latin America and the Caribbean

W. Roca, C. Espinoza, and A. Panta
Genetic Resources Conservation and Characterization Division, Centro Internacional de la Papa (CIP), Lima, Peru

This article provides a brief account of key developments in agricultural applications of biotechnology in Latin American and Caribbean (LAC) countries; it also focuses on the potential of developing value-added products from the biological diversity harbored in the region. Most agricultural biotechnologies involve tissue culture and DNA-based markers for germplasm conservation, production of disease-free planting material, and assistance to genetic improvement. More recently, LAC countries such as Argentina, Brazil, Colombia, Honduras, Mexico, and Uruguay have commercially grown transgenic crops. Advanced biotechnologies, such as genetic sequencing and microarray genomics, are differentially utilized in some LAC countries, with Brazil being at the forefront, for characterization, mapping, and trait screening for important crops and pathogens. There is great potential for the integration of these technologies with chemical analyses in bioprospecting biodiversity. Implementation of effective regulatory frameworks for access, genetic resource benefit sharing, and biosafety need urgent attention in most countries.

Key words: biodiversity, biotechnology, Latin American and Caribbean, sustainable utilization, valorization.

Introduction

The Latin America and Caribbean (LAC) region harbors major centers of origin and diversity for a number of organisms that support current world food production and industry. Agriculture and biodiversity are closely linked to biotechnology; the sustainability of protected biodiversity areas depends to a large extent on what transpires in intervened adjacent areas. Sound agricultural intensification can prevent further deterioration of protected landscapes. In traditional agricultural areas, modern biotechnology offers an opportunity not only to increase productivity and significantly reduce the use of off-farm chemical inputs, but also to enhance natural agro-biological systems.

Biotechnology has now become a preferred tool for adding value to biodiversity by allowing more effective identification and utilization of genes and derived products. Recent advances in genomic, proteomic and metabolomic research offer unprecedented opportunities for the search, identification, and commercial utilization of biological products and molecules in the pharmaceutical, nutraceutical, agricultural, and environmental sectors. This is crucial in a region where the agro-industry sector contributes 25% to the internal gross product (IGP), where the population is forecasted to reach 663 million (about one tenth of the world total) by 2020 (Food and Agricultural Organization of the United Nations, 2003), and where there is also a growing demand for food quantity and quality, for preventive control of human diseases, for mitigation of environmental degradation, and for increasing income by tackling new markets competitively.

Some studies on the status of plant biotechnology in the LAC region have been carried out (Table 1). The work of Roca, Amezquita, and Villalobos (1986), which included 23 countries and 82 groups, showed that the majority were involved in tissue culture research, with a smaller proportion (20%) initiating DNA-based applications, including molecular markers and genetic engineering. Ten years later, the Technical Cooperation Network on Plant Biotechnology for Latin America and the Caribbean (REDBIO) carried out another study of 15 countries, including 152 laboratories; an increased attention to plant genetic engineering and other DNA-based applications were highlighted in this study (Izquierdo, Ciampi, & De Garcia, 1995). More recently, Trigo (2000) described the institutional and human-resource capacities among 292 groups in 13 countries, and Dellacha et al. (2003) described the status of the biotechnological industry in LAC, including 430 firms, mostly in the agro-industrial area. These studies showed that the most advanced groups were in Brazil, Cuba, Mexico, and Argentina, with important highlights found in Chile, Colombia, and Costa Rica. A striking observation was that existing groups still need to take full advantage of strategic alliances for acquiring and sharing resources, knowledge, and products.

Table 1. Some characteristics of Latin American and Caribbean plant biotechnology research: summary of three studies.

Variables studied	1986	1999	2002[a]
Number of groups	82	292	86
Number of countries	23	13	10
Biotechnologies utilized:			
Cell & tissue culture	88%	29%	—
Molecular markers	20%	27%	—
Disease diagnosis	18%	20%	—
Genetic engineering	3%	14%	—
Microbial-based techniques[b]	10%	15%	—
Human resources assigned:[c]			
Postgraduate (total)	37%	42%	51%
PhD	20%	23%	28%
MSc	20%	19%	23%
Undergraduate	32%	41%	49%
Groups of plants investigated:			
Root and tuber crops	14%	7%	—
Fruit crops	9%	19%	—
Industrial crops	10%	10%	—
Pulses	9%	—	—
Cereals	8%	8%	—
Vegetables	5%	9%	—
Woody species and ornamentals	9%	8%	—
Investment in research and development:			
Public sector	60%	26%	62%
Universities (public & private)	20%	44%	9%
Private sector	20%	20%	28%
Major issues identified requiring attention:			
Strategic alliances	X	X	X
Access to new technologies	X	—	—
Private sector investment	X	—	X
Advanced training	X	X	—
Development of national biotech programs	—	—	X
Biosafety and IPR regulations	—	—	X
Public perception	—	X	X

[a] The 2001 study focused on industrial biotechnology only.
[b] Biopesticides, biofertilizers, and fermentation processes.
[c] Only professionals.

Following a brief account on the current status of agrobiotechnology, this paper draws attention to the use of biotechnology for the valorization of biological diversity—a promising potential of LAC countries for agro-industrial, health, and environmental development.

Agrobiotechnology in the LAC Region: Status Summary

Applications to Genetic Resources Conservation

Early attention given to tissue culture research (Table 1) allowed the establishment of in-vitro germplasm banks for several important crop plants in the LAC countries. Cryoconservation was developed to some extent for potato and cassava by the International Potato Center (CIP) in Peru and the International Center for Tropical Agriculture (CIAT) in Colombia, respectively, and for coffee somatic embryos by the Tropical Agronomic Research and Teaching Center (CATIE) in Costa Rica.

Genetic diversity analysis, using molecular markers, has improved the characterization and conservation of economically important crop germplasm, and recently has been extended to promising Amazonian and Andean species. Today, advanced biotechnologies (such as DNA microarrays) are beginning to impact genetic resource assessment and utilization research; however, because of the high investment and expertise required, these developments are limited to certain groups. They are currently being applied mainly in Brazil ("Brazil a new mecca for genomics?", 2002), but Mexico, Cuba, Venezuela, Chile (Ramirez et al., 2002), and Colombia are also developing genome research. Andean root and tuber crop biodiversity studies are underway in Peru (Table 3).

Applications to Plant Health and Propagation

Monoclonal antibodies, recombinant antigens, and molecular plant disease tests have greatly improved diagnostic systems and pathogen characterization. The most widely used technique for generating pathogen/virus free plants in the region involved the combination of thermotherapy and meristem tip culture. This tissue-culture-based application is still actively being used in most seed-production programs of the region. The CIP and CIAT pioneered the development of these techniques for generating and distributing healthy plant stocks of vegetatively propagated crops (e.g., potato, sweetpotato, and cassava). National programs and private groups of Brazil, Chile, Uruguay, Cuba, Mexico, Argentina, Colombia, and Peru have developed and commercialized these technologies, to variable extent, for the production of healthy seed.

Tissue-culture-based propagation techniques have been used in the region over many years (Table 1) for the multiplication of planting material of many econom-

Table 2. Genetically engineered crop plants grown in Latin American and Caribbean countries, 2003.

Country	Million ha	Crops and traits	Stage of development
Argentina	13.9	Glyphosate-tolerant soybean, Bt maize, ammonium glufosinate-tolerant maize, Bt cotton, herbicide-tolerant canola, herbicide-tolerant sugarbeet	Commercialization, field trials
Belize	—	Herbicide-tolerant soybean	Field trials
Bolivia	—	Herbicide-tolerant and insect-resistant cotton and soybean	Field trials
Brazil	3	Herbicide-tolerant corn, insect-resistant cotton, PVX-resistant potato, herbicide-tolerant rice, insect-resistant tobacco, glyphosate herbicide-tolerant soybean, herbicide-tolerant sugarcane, PRSV-resistant papaya, low lignine content eucalyptus, Golden mosaic virus-resistant beans, controlled-ripening coffee	Field trials, research, commercialization
Chile	—	Bt maize, herbicide-tolerant soybean, canola quality characteristics, herbicide-tolerant and virus-resistant sugar beet, tomato quality characteristics	Field trials, commercialization
Colombia	<0.05	Bt cotton, carnations, virus-resistant rice, insect-resistant cassava, cotton	Field trials, commercialization
Costa Rica	—	Herbicide-tolerant soybean, banana quality characteristics, virus-resistant corn	Field trials
Cuba	—	Fungus-resistant and virus (PVX, PVY and PLRV)-resistant potato, virus-resistant papaya, insect-resistant sweetpotato, insect-resistant sugarcane	Field trials
Honduras	<0.05	Bt maize	Field trials, commercialization
Mexico	<0.05	Glyphosate-tolerant soybean, PLRV-resistant potato, aluminium-tolerant maize and wheat, Bt cotton	Commercialization, field trials
Puerto Rico	—	Herbicide-tolerant soybean	Field trials
Uruguay	>0.05	Glyphosate-tolerant soybean, maize	Commercialization

ically important crop plants, such as roots and tubers, flowers, fruit trees, and others. These propagation techniques are now being standardized for a range of native plants of commercial value, such as forests and ornamentals.

Bioreactors and temporary immersion systems are now available for industrial plant multiplication; however, development of this technology is still incipient in the region. Important applications have been demonstrated for coffee somatic embryo multiplication at CATIE, for cassava multiplication, rice anther culture, and regeneration of genetically transformed cassava at CIAT, and for the regeneration and multiplication of potato clones at CIP (Tables 4 & 5).

Genetic Improvement Applications

For many LAC biotechnology groups, anther culture for haploid plant production and embryo rescue for hybrid plant production have been connected to crop improvement programs, such as those in Mexico, Colombia, Costa Rica, Uruguay, Chile, and Brazil for rice and grain legumes. Molecular marker-assisted selection has improved plant breeding through the use of tightly linked markers in assisted selection. Practical examples exist in the region for maize and wheat at CIMMYT; cassava, rice, and common bean at CIAT; potato and sweetpotato at CIP; and in the national programs of Brazil, Mexico, Uruguay, Chile, Colombia, and Costa Rica (Tables 4 & 5).

The LAC region has conducted 27% of the world's field trials of 24 transgenic crops (James, 2003). Argentina alone represents 21% and is second in the world in growing transgenic crops commercially; this has represented $200 million of profits to Argentina in 2000. Argentina, Brazil, Colombia, Honduras, Mexico, and Uruguay commercialize genetically engineered (GE) crops. Brazil officially approved GE crops for planting in 2003 and has already become the fourth in the world in growing GE crops. Colombia approved 10,000 hectares of commercial Bt cotton and carnations for export. Bolivia has carried out field trials for GE cotton and soybeans, and Honduras is growing GE maize for the first time (James, 2003; Table 2). In Mexico, the Savia firm has performed within the ten top worldwide (Solleiro & Castañon, 1999). Because the global market for transgenic crops is projected to reach $25 billion in 2010, this application area has generated large expectations in LAC countries. Biosafety and IPR regulations still have to be enforced in many countries for an effective and safe use of genetically engineered crops, espe-

Table 3. Genomic initiatives in Latin American and Caribbean countries.

Institution	Country	Organism	Project	Biotechnologies
EMBRAPA-CENARGEN (Genetic resources and biotechnology)	Brazil		Anotação Funcional Computacional de Proteínas	DNA microarrays, proteomics, genome comparison, computational genomics, phylogenetics profile
University of Campinas Genomics and Expression Laboratory (LGE), Rede Bahia	Brazil	*Crinipellis perniciosa* (pathognic fungus in *Theobroma*)	"Vassoura de Bruxa" Genome Project	Cosmid libraries, shotgun sequencing, bioinformatics
University of Campinas LGE	Brazil	Eucalyptus	Genolyptus	
University of Campinas LGE	Brazil	Hansenula polymorpha	*Hansenula polymorpha* Genome Program	DNA microarrays
Organization for Nucleotide Sequencing and Analysis (ONSA), Sao Paulo State Science Foundation (FAPESP), University of Campinas LGE	Brazil	*Xylella fastidiosa* of grapevine, *Leifsonia*, *Eucalyptus*	Agronomical & Environmental Genomes	
ONSA, FAPESP, University of Campinas	Brazil	Sugarcane	Sugarcane EST Genome Project	cDNA libraries, ESTs, DNA sequencing, data mining, bioinformatics, databases
ONSA, FAPESP	Brazil	*Xilella fastidiosa* (citric pathogen)	*Xilella fastidiosa* Genome Project	Cosmid libraries, shotgun sequencing, physical mapping, bioinformatics, functional genomics
ONSA, FAPESP	Brazil	*Xanthomonas citri*, *Xanthomonas* species	*Xanthomonas citri* Genome Project	Cosmid libraries, sequencing, proteomics, bioinformatics, genome comparison, phylogeny
Programa de Implantação da Rede Genoma do Estado do Rio de Janeiro (RioGene)	Brazil	*Gluconacetobacter diazotrophicus* (nitrogen-fixing bacteria)	Genome sequencing	Shotgun sequencing
Genomics Sequencing Program of Parana (GENOPAR)	Brazil	*Herbaspirillum seropedicae* (nitrogen-fixing bacteria)	Genome sequencing	
Biotechnology Institute, UNAM	Mexico	wheat, maize, rice	Osmotic stress ressistance, transgenics	DNA microarrays, genomics, CDNA libraries, BACS libraries
UNAM/Nitrogen Fixation Center Program of Computational Genomics	Mexico	Rhizobium etli	Bioinformatics of the Genome project of *Rhizobium etli*	Transcriptomics, proteomics, genomics, bioinformatics
National Center of Scientific research (CNIC)	Cuba	Sugarcane, maize, rice	Production of early-maturing sugarcane	Expression libraries, genomics, functional genomics
Project Genome Chile	Chile	Peach	Functional genomics in nectarines	ESTs sequences, functional genomics, macroarrays, proteomics (2-D gels)
Universidad Tecnica Federico Santa Maria	Chile	Grapevine	Functional genomics in grapevine	ESTs sequences, functional genomics, transcriptomes
United Nations University	Venezuela	—	Latin American Genome Biology Network	Genomics, bioinformatics

Table 4. Genetic resources under study at international and regional agricultural research institutions in Latin America and the Caribbean.

Institution	Genetic resources (# accessions)
International Center for Tropical Agriculture (CIAT; http://www.ciat.cgiar.org)	*Arachis* spp. (250), tropical forages (60), wild *Manihot* spp.(40), *M. esculenta* (5,541), *Oryza sativa* (260), wild *Phaseolus* spp.(69), *P.* vulgaris (27,458)
CIMMYT (http://www.cimmyt.org)	*Hordeum vulgare* (3), *Secale cereale* (54), *Triticum aestivum* ssp. *aestivum* (63,290), *T. turgidum* (50), *Zea mays* (17,807), *Z. perennis* (162)
CIP (http://www.cipotato.org)	*Arracacia* (33), *Canna indica* (21), wild *Ipomoea* spp. (939), *I. batatas* (4,143), wild *Lepidium* spp. (5), *L. meyenii* (31), wild *Oxalis* spp. (3), *O. tuberosa* (238), *Smallanthus sonchifolius* (28), wild *Solanum* spp. (1,354), *S. ajanhuiri* (11), *S. chaucha* (95), *S. curtilobum* (13), *S. juzepczukii* (26), *S. phureja* (136), *S. stenotomum* ssp. *goniocalyx* (46), *S. stenotomum* ssp. *stenotomum* (284), *S. tuberosum* ssp. *andigena* (2,567), *S. tuberosum* ssp. *tuberosum* (938), *S. tuberosum* x *andigena* (21), *Tropaeolum tuberosum* ssp. *tuberosum* (22), wild *Ullucus* spp. (2), *U. tuberosus* (255)
CATIE (http://www.catie.ac.cr/catie)	*Annanas comosus* (6), wild *Annona* spp. (10), *A. muricata* (50), wild *Bactris* spp. (2), *B. gasipaes* (646), wild *Bambusa* spp. (4), *Bixa orellana* (132), wild *Capsicum* spp. (829), *C. annuum* (274), *C. baccatum* (47), *C. chinense* (124), *C. frutescens* (229), *C. pubescens* (27), *Chrysophyllum cainito*(26), *Cocos nucifera* (2), wild *Coffea* spp. (14),*C. arabica* (1,623), *C. canephora* (56), *C. liberica* (15), wild *Cucurbita* spp. (392), *C. moschata* (1,546), *C. pepo* (201), *Dioscorea* spp. (73), wild *Lycopersicon* sp. (127), *L. pimpinellifolium* (20), *Manihot esculenta* (169), *Mauritia flexuosa* (2), *Musa* spp. (48), *Pachyrrhizus tuberosus* (28), wild *Phaseolus* spp. (100), *P. vulgaris* (895), *P. lunatus* (47), *P. dumosus* (31), *Solanum qiutoense* (14), other *Solanum* spp. (55), *Theobroma cacao* (687), *Vigna* spp. (149), *Zea mays* (402)

cially if their production is meant for the export market. The agricultural systems that prevail in significant sectors of the LAC region are characterized by a mosaic of continuous cropping systems, complex crop/pest management systems, and biological, cultural, and socioeconomic diversity, all of which need to be considered in the adoption strategies of any agricultural new technology, including genetically engineered crops.

Table 5. Biotechnologies utilized at international and regional agricultural research institutions in Latin America and the Caribbean.

Biotechnologies utilized	CIAT	CIMMYT	CIP	CATIE
Temporal immersion system	X		X	X
Cryoconservation	X		X	X
Somatic embriogenesis	X		X	X
Apomixis		X		
Genetic transformation	X	X	X	X
Genetic engineering	X	X	X	X
Isoenzyme markers	X			
Molecular markers	SCARs, SSR, AFLP, RAPD, SNP	SSR, AFLP, RFLP	SSR, AFLP, RFLP, SNP, RAPD	RAPD, AFLP
QTLs (quantitative trait loci)	X	X	X	
MAS (marker-assisted selection)	X			
cDNA libraries	X		X	
ESTs (expressed sequence tags)	X	X	X	
DNA microarrays	X	X		
Structural genomics		X	X	
Functional genomics		X	X	
Transcriptomics		X		
PQLs (protein quantity loci)		X		
Proteomics		X		
GIS	X		X	
Bioinformatics	X	X	X	X
Monoclonal and policlonal antibodies			X	
Biopesticides			X	

Currently, the most commercialized biotechnological product in the LAC region has been transgenic seed, but it has been concentrated basically in one country. The next in importance is the selling of virus-free stocks and seeds, and in third place are biopesticides and other agricultural bioinputs (Dellacha, 2003). Countries which have used modern biotechnologies like genetic engineering have had a higher value of their seed market (Brazil, US$1,200; Argentina, US$810; Mexico, US$350) than those using mature technologies like tissue culture (Bolivia, US$35; Ecuador, US$12; Trigo, Traxler, Pray & Echevarria, 2000).

Table 6. Biodiversity richness in some Latin American countries.

Country	Flowering plants	Birds	Amphibians	Butterflies	Mammals	NBI[a]
	Thousand species (rank)					
Colombia	45–51 (2)	1,815 (1)	583 (1)	3,100 (3)	456 (5)	0.935
Brazil	56–60 (1)	1,622 (3)	516 (2)	3,100 (2)	524 (1)	0.877
Peru	20–25 (9)	1,703 (2)	251 (7)	3,532 (1)	361 (6)	0.843
Ecuador	—	1,559 (4)	358 (3)	2,200 (7)	280	0.873
Mexico	18–30 (5)	1,050 (12)	282 (4)	2,237 (6)	502 (3)	0.928
Bolivia	18–20	1,360 (8)	155	— (4)	267	0.724

Note. Data from Institute A. von Humboldt (2003).
[a] NBI: National Biodiversity Index. This index is based on estimates of country richness and endemisms. Index values range between 1.000 and 0.000.

Human Resources and Funding

The FAO's 2000 report pointed out to a general weakness in the quantity and quality of regional biotechnology researchers: Only 40% of the limited number available were postgraduates, and only about 10% had doctoral degrees. Most researchers were biologists or agronomists, with very few specialized in key areas such as molecular genetics, molecular biology, protein engineering, molecular and industrial microbiology, or bioinformatics.

An aggressive program of personnel development needs to be implemented in most LAC countries in basic sciences and cutting-edge biotechnological applications—in particular, in the Central American and the Andean regions—otherwise any biotechnological program aimed at generating income and employment would face serious drawbacks. By 1999, the LAC region invested only 0.59% of the IGP in research and development, with Brazil, Chile, and Cuba showing the highest level. However, even these lagged behind countries like Canada (1.61%), France (2.18%), the United States (2.84%), and Japan (3.06%). Dellacha et al. (2003) reported that 62% of the scientific and technological activities in LAC were funded through the state's national science and technology councils, 28% by companies, and 9% by universities; funding coming from external sources was approximately 1%. State support and private investment for biotechnology research varies in the region. In some countries, it is minimal; for example, in Peru the 1998 funds from the state amounted only to 0.06% of the IGP, while in Brazil state funding was 0.86% in 1999.

Potential of Biotechnology for Biodiversity Valorization in the LAC Region

The LAC region concentrates major biodiversity hotspots of the world (Table 6). The region is also a center of origin and diversity of a number of species that sustain current world food supply (e.g., potato, sweetpotato, corn, tomato, beans, cassava, peanuts, pineapple, cacao, chili pepper, and papaya). Furthermore, the greatest number of flowering plants with unusual sources of compounds for food and agriculture, as well as for the biopharmaceutical, nutraceutical, cosmetic, and environmental industries, exists in this region (Table 7). This comparative advantage needs to be explored and sustainably utilized by integrating the emerging biotechnologies with the region's rich traditional knowledge on the properties and attributes of its biological resources. The world market for biological resource-derived ingredients and molecules in 1999 was US$925 billion for different sectors and industries (Inst. A.V. Humboldt, 2003).

Several LAC research groups have begun to work with native forest and medicinal species with the view to explore commercial opportunities in the use of natural ingredients (Table 7). Application of simple bioprocessing technologies offers a short-term approach for the production of sweeteners, flavor products, fruit juices, amino acids, pigments, vitamins, and antioxidants. For example, the Agroindustrial Group Backus S.A. in Peru has used camu-camu, an Amazonian fruit of the Myrtaceae family, for ascorbic acid extraction.

The nutraceutical and biopharmaceutical products have become the third and fourth most important markets for biological resource-derived products (Table 8). In order to tackle these emergent markets, new scientific specializations are being created in universities and industry worldwide. Some have resulted from the merging of former branches of science; for example, ethno-

Table 7. Some wild and cultivated plant biodiversity from Latin America and the Caribbean with current or potential use in the agricultural, food, health, nutraceutical, and environmental industries.

Biological resource	Ecosystem[a]	Key ingredients	Some reported properties
Maca (*Lepidium meyenii*)	H	Alkaloids, esteroids	Fertility, sexual disfunction, vigor enhancer
Mashua (*Tropaeolum tuberosum*)	H	Isothiocyanates, pigments	Antibacteria (*E. pilori*), antioxidants, insecticide
Yacon (*Smallanthus sonchifolia*)	H/L	Oligofructans	Low-calorie sweetener
Native potatoes (*Solanum andigena, S. stenotomum, S. goniocalix, S. curtilobum, S. juzepsuki, S. chaucha, S. Ajanhuiri*)	H	Pigments (anthocianins, xanthophylls, carotenoids)	Antioxidants, nutraceutic
Oca (*Oxalis tuberosa*)	H	Pigments, alkaloids	Antioxidants, nutraceutic, insect repelent
Arracacha (*Arracacia xanthorriza*)	H/L	Starch	Nutritive food for babies
Achira (*Canna edulis*)	H/L	Starch (large size grain)	Starch industry
Mauka (*Mirabilis expansa*)	H		Antiviral, antifungal
Sangre de grado (*Croton lechleri, C. perspiciosus, C. palanostigma, C. gossypifolium, C. draconoides*)	L	Pro-anthocianidins (catequine, epicatequine, galocatequine	Antiviral, cicatrizing
Matico (*Piper angustifolium, P. aduncum)*	H	Monoterpenes (camphor, camphenol, borneol, borneol-iso), sesquiterpenes (bisabolol-beta), phenil propanoid	Nutraceutic, anti-inflammatory, antitussive, anti-diarrheic, anti-*Trichomona vaginale,* antiseptic
Manayupa (*Desmodium molliculum*)	H	Steroids and organic acids	Mucous membrane anti-inflammatory
Sand flower (*Tiquilia paronychoides*)	H	—	Neuroglandular system anti-inflammatory
Agracejo (*Berberi vulgaris*)	H	—	Hepatovesicle anti-inflammatory
White flower (*Buddleja incana*)	H	—	Genitourinary anti-inflammatory
Canchalagua (*Schkuria pinnata*)	H	—	Anti-inflammatory, blood detoxicating
Andean grains (*Chenopodium quinoa, C. pallidicaule, Amaranthus cadatus*)	H	High protein content, saponins	Nutritive food
Tarwi (*Lupinus mutabilis*)	H	High protein content	Nutritive food
Ñuna (*Phaseolus vulgaris*)	H	High protein content	Nutritive food
Sangre de drago de Socotra (*Dracaena cinnaban)*	H/L	Pigments	Natural colorant
Tara (*Caesalpinea tintorea*)	H	Tannins	Anti-inflammatory, antiseptic, leather industry
Achiote (*Bixa orellana*)	L	Pigments	Natural colorant for food industry
Airampo (*Opuntia* spp.)	H	Pigments	Natural colorant
Boliche (*Sapindus saponaria*)	H	Saponins	Personal care, detergent
Atajo (*Amaranthus* spp.; wild kiwicha)	H	Iodine, proteins	Nutraceutical food
Molle (*Echinus molle*)	H	—	Insect repellent
Wild papaya (*Carica peruviana)*	L	Papaine	Food industry
Tomate de árbol (*Cyphomandra betacea)*	H/L	Micronutrients	Nutritive food
Uchuva (*Physalis peruviana*)	H	Vitamins A & C	Nutraceutic, micronutrients
Camu Camu (*Myrciaria* spp.)	L	Ascorbic acid	Food industry, pharmacological

Table 7. (continued) Some wild and cultivated plant biodiversity from Latin America and the Caribbean with current or potential use in the agricultural, food, health, nutraceutical, and environmental industries.

Biological resource	Ecosystem[a]	Key ingredients	Some reported properties
Pasifloras (*Passiflora* spp.)	H/L	Vitamins A & C	Nutraceutic, micronutrients
Lúcuma (*Pouteria caimita*)	L	Flavors, pigments, vitamins, fats	Nutraceutic, cosmetics
Chirimoyas (*Annona cherimolla*)	L	Vitamins A & C, calcium, phosphorous	Micronutrients, nutraceutic
Guanábana (*Annona muricata*)	L	Micronutrients	Food
Sauco (*Sambucus peruviana*)	H	Flavors, pigments, vitamin C	Antioxidant
Mora (*Rubus* spp.)	H	Flavors, pigments	Antioxidant
Chiles and rocoto (*Capsicum* spp.)	H	Capsisicum acid (alkaloid), ascorbic acid	Flavors, antiseptic
Sweetpotato (*Ipomoea batatas*)	L	Carotenoids, provitamin A	Micronutrients
Muña (*Minthostachys mollis*)	H	Essential oils	Spicy, insecticide, bactericide
Algarrobo (*Prosopis peruviana*)	L	Vitamins	Flavors, nutraceutic, syrup
Cotton (*Gosyppium* spp.)	L	Pigments	Textile industry
Wild anise (*Tagetes filifolia*)	H	Essential oils	Aromatic, diuretic
Coca (*Erytroxylum cocae*)	H	Alkaloids, vitamins, minerals	Stimulative drug, vasodilator, food industry
Pihuayo (*Bactris gasipaes*)	L	Carotenoids, pigments, fats	Micronutrients, food industry

[a] H—highland ecosystems; L—lowland ecosystems; H/L—highland and lowland ecosystems.

Table 8. Estimated annual global market for biodiversity-derived products, 2001.

Industry sector	US$ billion
Agricultural products	62
Functional foods	55.5
Herbal medicines & nutraceuticals	50.6
Pharmaceuticals	43.7
Biopharmaceuticals	12
Seeds	3.7
Personal care and cosmetics	2.9

Note. Data from Market analysis for utilization of biodiversity platforms in the Andean region through technological applications (report submitted to CAF), 2003. Available on the World Wide Web: http://www.caf.com/attach/9/default/Estudio1Analisis...-Español(verweb).pdf.

botany has joined with pharmacology to form ethnopharmacology. On the other hand, new tools are being developed for the automatization and miniaturization of genetic and chemical analyses and syntheses (e.g., robotics, DNA chips, combinatorial chemistry, liquid chromatography, mass spectrometry, X-ray spectrophotometry, nuclear magnetic resonance, among others). The so-called new "omic" sciences (functional genomics, proteomics, and metabolomics) and bioinformatics are improving the search of chemical principles from plant species to develop new target-specific drugs. Not only are specialized personnel and modern equipment needed to achieve scale-up capabilities in this field, but appropriate business management, including IPR (Table 9), are major factors that still limit commercial takeoff in the LAC region.

Since 1997, Brazil has implemented several genome projects in universities and private research laboratories under the management of a virtual institute, the Organization for Nucleotide Sequencing and Analysis (ONSA; "Brazil a new mecca for genomics?", 2002). The organisms selected include bacteria and plants important to Brazil's economy and also of global interest (e.g., sugarcane, *Xylella fastidiosa*, *Xanthomonas* species, and *Eucalyptus*). These studies involve high-throughput sequencing, functional genomics, proteomics, and transcriptomics, among other advanced technologies. The initial goal was the sequencing of the plant pathogen *Xylella fastidiosa*, which was achieved for the first time worldwide. Other efforts in the region are in Mexico, Cuba, and recently in Chile, where the national genome project will tackle the functional genomics of grapevine and peach (Table 3). A Latin American Genome Biology Network, sponsored by the United Nations University for Latin America and the Caribbean (UNU-BIOLAC), has been created with the objective of enhancing linkages among Latin American groups

Table 9. Current biosafety and intellectual property protection framework in LAC countries, 2002.

Country	Biosafety	Intellectual property
Argentina	yes	regulations enforced
Bolivia	yes	under development
Brazil	yes	regulations enforced
Chile	yes	regulations enforced
Colombia	yes	regulations enforced
Costa Rica	yes	existing laws
Cuba	yes	regulations enforced
Ecuador	yes	existing laws
Guatemala	yes	existing laws
Mexico	yes	regulations enforced
Paraguay	yes	regulations enforced
Peru	law without local norms	existing laws
Uruguay	yes	regulations enforced
Venezuela	under development	regulations enforced

working with high-throughput genomic technologies (Ramirez et al., 2002).

In 2003, a study in Andean countries (Bolivia, Colombia, Ecuador, Peru, and Venezuela) supported by CAF (Corporación Andina de Fomento) and CEPAL (Economic Commission for Latin America and the Caribbean) was initiated with the goal of analyzing biotechnological, institutional, and human-resource capacities involved in biotechnology research and development for biodiversity utilization and generation of biotechnological products and biotrades. The study also analyzes the global/regional market trends for their potential commercialization and eventually will offer recommendations and strategic guidelines in support of these countries to promote sustainable value-added transformation and commercialization of products derived from biodiversity and biotechnology.

The regional CGIAR centers, the CIP, CIAT, and CIMMYT, and the regional organization (CATIE) have played active roles for many years in the regional development of biotechnology applications to selected crop plants through the diffusion of advanced strategic technologies (including genomic), have offered technical and scientific training, and have developed collaborative work with national research institutions (Table 4). REDBIO has had, and continues to have, a critical role in developing biotechnology science and applications in the LAC region. We believe it is now time to turn attention to biodiversity-based biotechnology research and development. Another promising future role of biotechnology is the enhancing of natural biological systems, such as nitrogen fixation, photosynthetic efficiency, soil nutrient cycling efficiency, abiotic (drought, acidity, salinity) stress adaptation, and the reduction of off-farm inputs such as agrochemicals. All have far-reaching implications for sustainable agricultural systems in LAC agroecologies like the Andean region. At present, however, most commercial biological products used in countries like Colombia and Cuba have been elaborated using the bacterium *B. thuringiensis*, the fungi *Beauveria*, *Metarhizium,* and *Paecilomyces*, and baculoviruses.

Strengthening Biotechnology and Biodiversity Research in the LAC Region

In recent years, private investment in agricultural R&D has increased, particularly in countries where effective and transparent regulatory frameworks are in place and comparative research infrastructure and qualified human resources exist. A dynamic biotechnological industry, with clusters of companies and public research institutions, has begun to emerge in some LAC countries.

Joint public/private ventures have explored collaborations to address bioproduct market demands. One example is a bioprospecting collaboration, under an ICBG project, between the Aguaruna community of Peru, three universities, and the G.D. Searle Corporate Partnership, to apply ethnomedicinal approaches for examining plant biodiversity based on the Aguaruna pharmacopeia and involving a wide range of human diseases and syndromes. Patent applications have been filed as a result; benefit sharing with the communities has been included (Lewis, Lamas, Vaisberg, Corley, & Sarasara, 1999). Another ICBG project in Panama is searching new bioactive compounds against cancer and the tropical parasites causing malaria, leishmaniasis, and Chagas' disease, through a collaboration between Smithsonian Tropical Research Institute, several universities in Panama and one in the United States, and Novartis. Another example is the Minas Gerais biotechnological cluster comprising more than 30 enterprises under the leadership of BIOBRAS S.A., with annual sales of R$160 million. In Cuba, the Biotechnological West Pole of La Havana comprises more than 40 specialized biotechnology centers (Dellacha, 2003); others include the BioTrade initiative for the promotion of biodiversity-derived products and services in Colombia, under the leadership of the Alexander von Humboldt Institute, and the emerging companies in Amazonia supported by UNCTAD-Bolsa Amazonica-IavH (Inst. A.V. Humboldt, 2003).

The adoption of intellectual property and biosafety regulations has recently been promoted, but management and enforcement varies among LAC countries (Table 9). Chile is the only country where biotechnological processes can be patented. Microorganisms can be patented in Brazil and Mexico, but neither microorganisms nor genes can be patented in the Andean countries. In most countries, UPOV-type plant variety protection systems exist. Stimulation of investments and facilitation of the acquisition of technologies through collaborative partnerships should go hand-in-hand with mechanisms to link the research with the holders of biological resources. Governments can offer tax and other incentives to investors; these incentives should encourage the sharing of the derived benefits with the research partners and with the traditional curators of genetic resources.

Finally, it is relevant to mention that food insecurity in large sectors of the LAC region is a consequence of inadequate social, economic, and technological development. The new biotechnologies open a range of opportunities for increasing biodiversity-based product diversification. It is necessary to bear in mind not only the local socioeconomic context, but also the level of export/import of agricultural and biodiversity derived products; the importance of the small, medium, and large agro-industry in the economy; the country's research and technological capacities; and the existence of a legal framework that stimulates biodiversity conservation and utilization. The situation of the resource-poor farmer should be taken into account, to make sure that the benefits of modern biotechnologies reach this important sector—currently a majority in some LAC countries.

References

Brazil a new mecca for genomics? (2002). *Embnet.news*, *7*(1), 3-4. Available on the World Wide Web: http://www.embnet.org/download/embnetnews/emnn71.pdf .

Dellacha, J., Lionel, G., Ahumada, J., Castañón, R., Solleiro, J.L., & Verástegui, J. (2003). *La Biotecnología en América Latina: panorama al año 2002*. Ottawa, Canada: CamBioTec (Iniciativa Canada-America Latina en Biotecnología para el Desarrollo Sustentable).

Food and Agricultural Organization of the United Nations. (2003). *FAOSTAT 2003* [database]. Rome, Italy: Author. Available on the World Wide Web: http://apps.fao.org.

Instituto Alexander von Humboldt. (2003). *Qué es biocomercio sostenible?* Bogotá, Colombia: Author. Available on the World Wide Web: http://www.humboldt.org.co/biocomercio.

Izquierdo, J., Ciampi, L., & De Garcia, E. (1995). *Biotecnología apropiable: racionalidad de su desarrollo y aplicación en America Latina y el Caribe*. Santiago, Chile: FAO Regional Office for Latin America and the Caribbean.

James, C. (2003). *Preview: Global review of commercialized transgenic crops: 2003* (ISAAA Briefs No. 30). Ithaca, NY: International Service for the Acquisition of Agri-biotech Applications. Available on the World Wide Web: http://www.isaaa.org/Publications/briefs/briefs_27.htm.

Lewis, W., Lamas, G., Vaisberg, A., Corley, D.G., & Sarasara, C. (1999). Peruvian medicinal plant sources of new pharmaceuticals (international cooperative biodiversity group-Peru). *Pharmaceutical Biology*, *37*(supplement), 69-83.

Ramirez, J.L., Gonzales, A., Cantú, J.M., Chavez-Crooker, P., Leya, J.C., Blamey, J.M., Cortes, H., & Holmes, D. (2002). Latin American genome initiative: The creation of a network and web-based resource to aid and nurture genome biology in developing countries. *Electronic Journal of Biotechnology*, *5*(3).

Roca, W.M., Amezquita, M.C., & Villalobos, V.M. (1986). Estado actual y perspectivas de la bitecnologia agrícola en America Latina y el Carible. *Memorias del Seminario Internacional BID-CIAT*. Cali, Colombia: International Center for Tropical Agriculture.

Solleiro, J.L., & Castañon, R. (1999). Technological strategies of successful Latin American biotechnological firms. *Electronic Journal of Biotechnology*, *2*(1), 10-19. Available on the World Wide Web: http://www.ejbiotechnology.info/content/vol2/issue1/full/4/bip/index.html.

Trigo, E.J., Traxler, G., Pray, C.E., & Echevarria, R.G. (2000). *Biotecnología agrícola y desarrollo rural en América Latina y el Caribe: Implicaciones para el financiamiento del BID* (RUR-107). Washington, DC: Inter-American Development Bank. Available on the World Wide Web: http://www.iadb.org/sds/doc/rur-107S.pdf.

Trigo, E.J. (2000). The situation of agricultural biotechnology capacities and exploitation in Latin America and the Caribbean. In M. Qaim, A.F. Krattiger, & J. von Braun (Eds.), *Agricultural biotechnology in developing countries: Towards optimizing the benefits for the poor*. Durdrecht, The Netherlands: Kluwer Academic Publishers.

Acknowledgment

The authors wish to thank Dr. Nigel Taylor for his valuable comments in reviewing this paper.