

# Costa Rica: Challenges and Opportunities in Biotechnology and Biodiversity

---

*Ana Sittenfeld, Ana Mercedes Espinoza, Miguel Muñoz, and Alejandro Zamora*

Modern biotechnology in agriculture came into prominence in the 1990s. From 1986 to 1997, approximately 25,000 transgenic crop field trials were conducted in 45 countries on more than 60 crops with 10 different agronomic traits. Seventy-two percent of all transgenic field trials were conducted in the United States (James 1997). Approximately 40 percent of field trials being conducted in developing countries are for virus resistance, the balance being for herbicide-resistance crops (25 percent), and for insect resistance (25 percent) (Sasson 1999). By late 1997, 48 transgenic crops involving 12 cultivars and six traits were approved for commercialization in at least one country. More than 90 percent of the owners of this technology were private-sector operators (James 1997). The crops included soybean, cotton, oil-seed rape, potato, corn, tomato, papaya, and squash. Agronomic traits included insect, virus, and herbicide tolerance, delayed ripening, male sterility, and changes in oil composition (Nutfield Council on Bioethics 1999; Sasson 1999). Research on the genetic modification of rice, cassava, banana, oil palm, yam, and sorghum is being undertaken in public and private sector institutions (Krattinger 1998; Simon Moffat 1999).

Agricultural biotechnology is being adopted at very high rates. In 1998, approximately 28 million hectares were planted with transgenic crops, around 60 percent of this acreage being in the United States, followed by China and Latin America. This figure was up from 11 million hectares in 1997 and 1.7 million hectares in 1996

(Sasson 1999). Argentina grew 4.3 million hectares of transgenic crops in 1998, a three-fold increase from 1997. Europe planted a small acreage of genetically improved (GI) crops: about 8,100 hectares of transgenic corn in 1997 mainly in France and Spain (Nutfield Council on Bioethics 1999; Sasson 1999). In addition more than three-quarters of the cheese produced in the US is made from a gene-spliced version of an enzyme called chymosin (Miller 1999).

The principal benefits of transgenic crops include more flexibility in crop management, decreased dependence on conventional insecticides and herbicides, and higher yields. In 1997, the economic benefit to U.S. farmers was estimated at US\$133 million for *Bacillus thuringiensis* (Bt) cotton, US\$119 for Bt corn, and US\$109 million for herbicide-tolerant soybean, with an overall total of US\$381 million, up from US\$159 million in 1996. In a 1997 survey of the US Corn Belt, Bt corn produced an average of 32.8 bushels more per hectare than did non-Bt corn. Corn productivity is around 388 bushels per hectare, showing yield improvements of 10 percent and reductions of herbicide use of up to 40 percent (Holzman 1999). A study produced by the U.S. National Center for Food and Agricultural Policy (Washington, D.C.), estimates that new genetically improved corn raised yields in the United States by 47 million bushels on 1.6 million hectares in 1997 (a year of high corn borer infestation) and by 60 million bushels on 5.8 million hectares in 1998. Around 0.8 million fewer hectares of corn were sprayed with insecticides as a result of the tech-

nology. For cotton, yields were up to 38 million kilograms and 2.05 million fewer hectares were treated with insecticide (Business and Regulatory News 1999).

### Challenges

The initial commercial goals of agricultural biotechnology were directed at the markets of the industrial world. There is a growing realization, however, that agricultural biotechnology could make a valuable contribution toward solving the urgent problem of food supply, protecting the environment, and reducing poverty in developing countries. There is no doubt that agricultural biotechnology has opened up new possibilities, particularly in crop and livestock development. The question remains as to just how agricultural biotechnology will improve livelihoods and increase the standard of living in developing countries.

A sustainable strategy to provide food security for a growing population must promote biodiversity conservation, and avoid further habitat loss of natural ecosystems. The strategy must also seek to: reduce unsustainable technologies such as the overuse of chemical fertilizers and pesticides, unsustainable irrigation procedures, and soil preparation methods that promote soil erosion; increase nutritional composition; reduce postharvest storage losses; and increase production from the present 2 billion metric tons per year to 4 billion. The strategy must also deal with issues of ethics, biosafety, and intellectual property rights (IPR) in the use of new biotechnologies.

Food security today must be defined in terms of grains, meat, and milk production and supply. Over the next 20 years there will be an increase in demand for meat, with most of the increased demand coming from developing countries, thus making investment in livestock research a necessity. The relative importance of different livestock species varies: cattle are generally more important for Latin America and the Caribbean, small ruminants in sub-Saharan Africa, small ruminants and buffalo in South Asia, and pigs and poultry in East Asia and Latin America (Delgado and others 1999).

Good science and technology development is fundamental to the successful use of biotechnol-

ogy in agriculture. Developing countries are not homogeneous, however, in terms of scientific capabilities, social structures, and economic goals, so there is not a single solution for all countries. There are countries with very little capacity in agricultural biotechnology. They require different strategies than countries with an up-to-date biotechnology program. The latter countries may also have a national policy and strong connections within the country between the public and private sectors, and between both those sectors and their equivalent sectors in more advanced countries (Brink, Prior, and DaSilva 1999). It is not surprising, therefore, to find first-class biotechnology laboratories in China, India, Thailand, Brazil, Argentina, Mexico, Egypt, and South Africa, which are perfectly capable of competing in the world of agricultural biotechnology.

In a recent study, Solleiro and Castañón (1999) indicate that Latin America has arrived late on markets for biotechnology products and services, a situation related to an industrial structure that is traditionally reluctant to introduce changes, and has little capacity for R&D. The authors give several explanations: Most R&D in Latin America is conducted at universities and public sector institutions, with minor participation of the industrial sector; human resources are not sufficient to cover all demands, and biotechnology in the region is not structured in a multidisciplinary way with capacity in molecular biology as well as management and marketing. A few successful efforts have incorporated competitive strategies on the intelligent management, combining in-house skills with excellent capabilities to locate, acquire, and assimilate external technologies.

A significant portion of the improvements in agricultural biotechnology are being developed by and/or controlled by a few major multinational companies, making it more difficult for developing countries to access know-how in this area. For many of the food production companies the objective is to become more integrated by promoting vertical coordination of food systems, from the field to the supermarket. Different forms of acquisitions, mergers, and alliances continue to be a dominant characteristic of the biotechnology industry (Thayer 1998). By 1998, companies that were primarily chemical in origin had taken over most of the seed business.

Through joint ventures and acquisitions, Monsanto and DuPont now market over half of the seeds for the two largest U.S. crops, soybean and corn (Thayer 1999).

### *Intellectual Property Issues*

Patenting and IPR are promoting privatization of scientific research in agricultural biotechnology, and might increase the gap of biotechnology know-how and its applications between developing and industrial countries (Serageldin 1999). Alternatives for developing countries include increasing research capacities at national institutions and at the CGIAR centers. This will allow the development of their own tools and know-how, which could be protected by IPR, and to acquire the necessary negotiation power to exchange licenses and implement strategic alliances with the private sector. The provision by donors of free licenses, acquired from the private sector and academic institutions, for basic enabling biotechnologies should also be considered when supporting projects in developing countries and CGIAR centers. Obtaining free licenses from the private sector, to be applied in providing solutions to tropical crops that are not on the agenda of industries, offers another alternative for developing countries. In general, learning how to use IPR as a tool to advance biotechnology in developing countries, together with public and private investment, as well as new and imaginative public-private collaboration, is needed to promote technology transfer and better use of resources.

Some arrangements involving transfer of proprietary technologies by the private and public sectors in industrial nations, without royalties, to developing countries are already taking place (Krattiger 1998). The benefit for developing countries is obvious; by increasing crop yields, new genetically improved crops reduce the constant need to clear more land for producing food; seeds designed to resist drought and pests would be especially useful in tropical countries, where crop losses are often severe. Scientists in industrial countries are already working with colleagues and individuals in developing countries to increase yields of staple foods, to improve quality for better market acceptance, and to diversify

economies by creating new exports (Simon Moffat 1999).

### **Opportunities and Constraints**

Biodiversity-rich countries can take advantage of their biological/genetic resources from wildland diversity, locally adapted varieties and races, and wild relatives of crops to increase yields. This can be performed by applying agricultural biotechnology tools, implementing bioprospecting activities, and by establishing partnerships with public and private sector institutions in industrial and developing countries, including the CGIAR centers. Required investments in infrastructure are much lower than for any other high technology field, with the exception of software development.

### *Linking Biodiversity and Biotechnology*

Several countries and institutions are implementing bioprospecting agreements with the private and public sector, based on the opportunities and obligations offered by the Convention on Biological Diversity, and on the new developments in biotechnology and molecular biology, which are rapidly generating new tools and bioproducts. Bioprospecting collaborations are occurring in both developing and industrial countries (Sittenfeld 1996; Varley and Scott 1998). In this process, the definition of policies on access to genetic resources by governments and nations, as part of well-planned bioprospecting frameworks, are of particular importance for the success of national programs. These activities integrate the search for compounds, genes, and other nature-derived products with the sustainable use of biological resources and their conservation, along with scientific and socioeconomic development of source countries and local communities.

Agricultural biotechnology, specifically the search for new genes for plant improvement, offers advantages to biodiversity-rich countries compared to pharmaceutical research. Infrastructure and capital equipment costs are higher for the pharmaceutical area than for agriculture research (Tamayo, Nader, and Sittenfeld 1997). The need for alternatives to production and protec-

tion of crops and livestock and the increasing capacity in biotechnology (for example, differential gene expression techniques and genetic engineering), offer new opportunities for bioprospecting. Biotechnology can facilitate the transfer of several traits from wild biodiversity into cultivated crops. However, as with traditional plant breeding, there is a need to select the precise traits that consumers would reward in the market (Carter 1996). Advances in biotechnology also provide choices of diversity beyond traditional use of *ex situ* collections in germplasm banks. It is important to incorporate *in situ* collections (in the form of wild biodiversity) into agricultural research. Together with this concept, the need to develop innovative systems to connect to agricultural practices, biodiversity conservation and intelligent use of biological resources becomes apparent (Sittenfeld and Lovejoy 1996; Sittenfeld 1998).

Many of the advances in agricultural biotechnology are developed in industrial countries, in close proximity to growing biotechnology companies, and therefore favor the agricultural practices of the industrial countries. This may pose a problem for the primarily agricultural economies of several countries in Latin America, and other developing countries, because these developments may displace or transfer the production of these countries to the farm fields of the industrial countries, or even possibly to industrial bioreactors (Tamayo, Nader and Sittenfeld 1997). The concept of modern biodiversity prospecting, already proved in drug research (Sittenfeld and Villers 1993, 1994), offers an alternative to this threat by transferring biotechnology to developing countries in exchange for access to their biological resources. This will enable developing countries to use their own biological resources while retaining a competitive edge with industrialized countries. We can find examples of this practice in Mexico, Surinam, Peru, Argentina, Chile, and Costa Rica. The Instituto Nacional de Biodiversidad (INBio) in Costa Rica is negotiating agreements with scientific research centers, universities, and private enterprise that are mutually beneficial to all parties (Sittenfeld 1998). These pioneering agreements provide significant returns to Costa Rica while simultaneously assigning an economic value to natural resources, and providing a new source of income to sup-

port bioechnology and the maintenance and development of the country's Conservation Areas.

Linking biotechnology and biodiversity through modern bioprospecting, requires the creation and implementation of adequate frameworks integrating favorable macropolicies, biodiversity inventories and information systems, technology access, and business development. The principle of bioprospecting may be simple, but the link between biotechnology, biodiversity conservation, and its sustainable use requires several considerations, including: a realization that a wider range of skills are required for research, product development, and approval; the creation, use, and management of multidisciplinary teams dealing with the complexities of legal and regulatory frameworks for biotechnology and biodiversity conservation and use; and the use of advanced applications of biotechnology to broader arrays of bioresources. Finally, understanding the opportunities and problems derived from international collaborative research and the linkages with commercial organizations represents a key point for favorable bioprospecting activities (Sittenfeld, Lovejoy, and Cohen 1999).

## **The Costa Rica Experience**

### *Importance of Agriculture*

Agriculture has been one of the most important sectors for the economy of Costa Rica, promoting democracy, national values, and political stability. Agricultural expansion, however, has resulted in poor natural resource management, with low value-added prices for most of the crops (Mateo 1996). The agricultural sector, although still contributing about 18 percent of the GNP and representing 70 percent of the total exports from 1970 to 1997 (Proyecto Estado de la Nación 1998), is currently undergoing changes caused by shifts and pressures of globalization, and fluctuating export prices in coffee and banana. A few successful exceptions are niche export markets for nontraditional products such as high value-added vegetables, fruits, and ornamentals (Mateo 1996). In 1997, agriculture exports accounted for US\$1.7 billion, although the size of the crop area diminished 32 percent from 179,034 hectares in 1970 to 120,118 in 1997. The active population in

the agricultural sector dropped from 25.3 percent in 1990 to 20.2 percent in 1997.

Research in agriculture has generated a number of useful technologies, contributed to national food security, and developed successful research systems on a few selected export crops such as coffee and banana. However, agricultural research has attempted to maximize production using models based on high inputs that caused pollution and contamination of land, water, and animal life (Mateo 1996). Importation of pesticides and herbicides increased six-fold in three years from 13,770 kilograms in 1993 to 60,886 kilograms in 1996. The use of pesticides on crops such as banana in Costa Rica has led to increasing numbers of poisoned field workers, higher than the numbers reported for other Latin American countries, the United States or Europe (Proyecto Estado de la Nación 1998).

#### *Conservation Strategies*

Costa Rica is a small country of 51,000 square kilometers that has enjoyed a long history of conservation. The accelerated growth of protected lands, coupled with deforestation and lack of institutional coordination, led to the formulation of a National System of Conservation Areas (SINAC) in 1986. Today SINAC comprises a system of clearly defined protected areas encompassing about 25 percent of the national territory (1,266,395 hectares in 1997), including National Parks, Forestry Reserves, Wildlife Refuges, and other means of protection under the administration of the Ministry of the Environment and Energy (MINA). Biodiversity in protected areas represents a major renewable resource and a potentially powerful engine for Costa Rica's intellectual and economic development (Mateo 1996; Sittenfeld 1996). Conservation areas are the main attraction for tourism, an industry that generated US\$719 million in 1997. Total exports in 1997 were US\$3.3 billion, indicating that protected areas are contributing to the economy in a substantial manner.

Having a quarter of its territory separated for wildland protection, and realizing that only 15 percent of the soils are adequate for agriculture (Proyecto Estado de la Nación 1998), Costa Rica needs to find ways to take advantage of its

biodiversity. It is a major challenge for sustainable development to find innovative ways to link conservation and biotechnology to increase agricultural production on less land, with lower pesticide use, and to maximize the benefits of bioprospecting.

#### *Biotechnology in Costa Rica*

*Rice Biotechnology Program at CIBCM.* Rice is the most important staple crop in Costa Rica, providing almost one-third of the daily caloric intake, with a per capita consumption of 55 kilograms/year. Production is based on rainfed and irrigated rice varieties developed several decades ago at the CGIAR-supported Centro Internacional de la Agricultura Tropical (Cali, Colombia). However due to a narrow genetic background, all the varieties are susceptible to similar pests and diseases such as planthoppers, rice hoja blanca virus, and rice blast fungus *Magnaporthe grisea*, as well as physiological disorders such as iron toxicity and zinc deficiency.

Because of a lack of resistance or tolerance to the factors mentioned above, the use of pesticides and fungicides has increased costs, which reduces profit margins and competitiveness of rice production in Costa Rica. Moreover, yield has remained fixed at 4.5 metric tons/hectare, leading to a strong dependency on international markets. A strategy based on pesticide spraying is also leading to pollution of water and wildlife refuges. Weed control, especially of red rice, a complex of *Oryza* species, represents nearly one-third of production costs.

The Rice Biotechnology Program has been supported by several institutions, including the Rockefeller Foundation and the Costa Rican-United States Foundation for Cooperation (CRUSA). It is centered on the use of biotechnology to make biodiversity available for crop improvement and to diminish or eliminate some constraints to rice production in Costa Rica. The strategy includes the molecular characterization of wild rice germplasm found in the country, which may harbor useful agronomic traits for future use in crop improvement. A second approach is bioprospecting for bacterial genes with insecticide activity isolated from different genera, such as *Bacillus thuringiensis*, *Photorhabdus* spp.

and *Xenorhabdus* spp., in different ecosystems. Isolated genes might be incorporated into the rice genome through genetic engineering. The strategy also includes genetic characterization of *M. grisea* lineages, in both cultivated and wild rice species to define sources of disease resistance.

Facilities were developed for plant genetic engineering at the CIBCM to offer a new tool to rice breeding programs. The first attempt at genetic transformation of rice was focused on the development of commercial rice cultivars resistant to hoja blanca, using viral genes and modified versions of those genes, which upon expression in plants may induce tolerance or resistance to the disease. This project started in 1989, with the molecular characterization and sequencing of the rice hoja blanca virus (RHBV), the development of plant tissue culture protocols for regeneration of Costa Rican "indica" rice varieties, and epidemiological studies on transmission and dispersion of RHBV by its insect vector, the planthopper *Tagosodes orizicolus*, which is also a pest of rice. Transgenic plants were produced using the RHBV coat protein gene as well as modified versions of the gene. The bacterial minichromosome used as a transformation vector included a bacterial gene to detoxify the herbicide glufosinate. This gene renders the plant resistant to the herbicide and is currently used for selection of transformed calli as well as in regenerated plants and their progeny. Herbicide-resistant plants may offer an alternative to control weeds, since a broad spectrum of them may be affected by the herbicide without harming rice plants.

Biological tests are conducted to demonstrate that the expression of RHBV capsid protein in transgenic plants is leading to resistance against the disease. Preliminary experiments are showing the lack of viral symptoms in transgenic plants; in order to determine whether the expression of the new trait is stable and inherited to the offspring, these lines will be tested in field trials during 2000-01.

Since a delphacid transmits the RHBV, it would be desirable to have genes that may affect *T. orizicolus*. We have conducted transformation experiments for expression of a lectin (GNA) that has anti-planthopper activity. The lectin gene was modified to achieve high levels of expression in the phloem tissues where the insect feeds, and

transgenic plants will be tested shortly under greenhouse conditions. This strategy plans to lead to cultivars containing two levels of resistance to hoja blanca disease, one against the virus and the other against its insect vector.

In addition to that work, a set of different genes is currently being transferred to rice cultivars. These genes include resistance to bacterial blast (*Xanthomonas oryzae*), the viral replicase gene against RHBV, and protein inhibitors for insect control. Several other genes activated during stress (drought and salinity) are going to be used in rice transformation. The ultimate goal is to pyramid genes on several commercial cultivars, which may be used in rice breeding programs.

The population of Costa Rica is increasing and cultivated land area is diminishing, so our ultimate goal is to increase yield per area through the use of biotechnology. In the long term we expect to have a pool of useful genes from wild rice relatives, bacteria, or even nonrelated plants, and to transfer them to commercial rice cultivars. Wild rice species have proved to be useful resources for enriching the genetic pool of cultivated rice. Interspecific crosses with *O. rufipogon* have increased yield up to 20 percent. Also, the Xa21 gene from *O. longistaminata* has been cloned and introduced into the rice genome, thus conferring the plants with resistance to *Xanthomonas oryzae*. Some of the characteristics that could potentially be used for the improvement of rice are: pests and pathogen resistance, higher protein content, plant vigor, tolerance to high metal concentrations, salinity, and soil acidity.

The Rice Biotechnology Program includes research to identify, map, and characterize the native relatives of rice that occur in Costa Rica. This research is conducted at CIBCM in collaboration with the International Rice Research Institute (IRRI), Manila, Philippines. The location of the plants was recorded with a geographic positioning system (GPS), and the distribution of wild rices was correlated to a series of ecological and geographical variables. The identification and characterization of the wild species were done by morphological methods, and the genetic variability of these species is being studied using rice microsatellites and isozymes.

Populations of three of the four *Oryza* species reported for tropical America have been found

in natural ecosystems throughout the country, accounting for three of the six described genome types of *Oryza*. Of these, *O. latifolia* is the most variable, abundant, and widely distributed. *Oryza grandiglumis* and *Oryza glumaepatula* are reported for the first time for Costa Rica. These two species have restricted distributions and need to be preserved, since they are not appropriately protected at the moment. Furthermore, two native populations of putative sterile hybrids that reproduce asexually have been found. Multivariate discriminant analysis revealed significant morphological differentiation of the species found. It also made clear the differentiated and intermediate position of the putative hybrids, one believed to have originated from the interspecific cross of *O. glumaepatula* and *O. grandiglumis*. *Oryza rufipogon*, native of Asia, and *O. glaberrima*, from Africa, have also been found in different rice plantations around the country, but not in natural habitats. These plants, now considered weeds, may also constitute valuable genetic resources for future use.

*Oryza latifolia* is a tetraploid species with a CCDD genome type. It occurs in a wide range of zones, soil types, and weather regimes, from 0 to 650 meters. A principal component analysis showed that there is significant differentiation of some of the populations of this species, mainly those from the Atlantic and Pacific slopes of Costa Rica. Isozymes have revealed genetic differentiation in the populations of this species, and a correlation between morphological and genetic variability has been observed. Some populations have agronomically important traits, such as drought and salinity tolerance, resistance to planthoppers, and shorter heading time. *Oryza grandiglumis* (CCDD genome) is a robust plant that occurs only in Caño Negro Wildlife Refuge. It has the biggest seed of the native *Oryza* species and it may have tolerance to *M. grisea*. There are two populations of *O. glumaepatula* located in unprotected marshlands in northern Costa Rica. This species belongs to the *O. sativa* group (AA genome), thus being the closest native relative of cultivated rice. Microsatellites are being used to assess the genetic diversity and structure of this species. The population at the Medio Queso River has two alleles per locus, whereas the one at Guanacaste is fixed at both markers studied.

There is, as well, a cline at the Medio Queso population, which could be the result of a limited gene flow between subpopulations. This information will be useful to design *in situ* conservation strategies for these species, as well as in the breeding plans and in risk assessment for the introduction of genetically improved rice. Pathogens and other organisms related to these wild species are now being identified. Tolerance to biotic and abiotic stress factors will be an important characteristic in selection of germplasm to be used in interespecific crosses, and in selection of offspring.

#### *Intellectual Property Issues*

Two main concerns have arisen out of this experience. First, IPR on the vectors and genes used in the transformation process may be under patent protection in the hands of private companies and academic institutions. This principle also applies to patents on technologies and tools used, such as plant transformation systems, selectable markers, and gene expression technologies. When broad patents, or patents on basic research, are obtained by the private sector, the consequences for public research products are important. This is the case for biolistics (DuPont), *Agrobacterium*-mediated transformation (Japan Tobacco), and coat protein-mediated resistance (Monsanto). If those technologies are used only for research purposes, there is a general agreement that no infringement occurs. However, this is not the case when research is translated into products in the marketplace. This situation is affecting the commercial development of new genetically improved plants in Costa Rica. In addition, the Patent Law of 1983 excludes the protection of biotechnology products and procedures. By 2000 the law is expected to be changed to meet TRIPs requirements.

In Costa Rica, as in other countries, the distribution channels and agricultural extension in the public sector to reach farmers fields are in a process of change toward privatization. Broad IPR protection of enabling technologies in the hands of the private sector might have serious impact, as seed distribution channels are undergoing privatization around the world (Spillane 1999).

### *Regulatory Issues*

The second concern is related to biosafety regulations and the risk of using genetically improved rice cultivars in tropical environments. No documented experience on this topic has yet been published, to the best of our knowledge. It is one of the most contentious arguments against the use of genetically improved plants in the tropics, since it is assumed that wild relatives might under specific conditions hybridize and give rise to a new hybrid that may pose a threat to agriculture if it behaves as a weed. No scientific evidence has been presented to support this argument, though a large body of speculation is shaping the opinion about plant biotechnology among consumers and even regulatory offices. The mapping of native relatives of rice species in Costa Rica is providing important information to select field trial locations and crop areas. Conducting this type of study, in connection with the production of different genetically improved rice plants, offers an interesting model to manage risks associated with agricultural biotechnology developments. It is important to note that in 1997 Costa Rica included biosafety regulations in its Phytosanitary Protection Law No. 7664.

Will Costa Rica benefit from agricultural biotechnology? The answer may lie more heavily on the solution of the two concerns of intellectual property and biosafety above mentioned than on the ingenuity of the plant breeders and molecular biologists.

### **Bioprospecting**

The Bioprospecting Program of Costa Rica's National Biodiversity Institute (INBio), established in 1989, is a private nonprofit research institute. Its mission is to promote greater awareness of the value of biodiversity, and thereby promote its conservation and improve the quality of life of Costa Rican society. The institute generates knowledge about biodiversity and disseminates and promotes the sustainable use of biological and genetic resources. Several of INBio's programs, including its National Biodiversity Inventory, Bioprospecting, Information Management, and Information Dissemination and Conservation Program, document what biodiversity exists in Costa Rica, where it can be found, and how the

country can find sustainable, nondamaging ways to use it and to conserve it (Tamayo, Nader, and Sittenfeld 1997). The collaborative agreement established between INBio and the Ministry of the Environment and Energy (MINAE), provides the framework for inventory and bioprospecting activities in collaboration with the SINAC. INBio, through specific access permits, collects samples for its Inventory and Biodiversity Prospecting Divisions and shares intellectual and monetary benefits with MINAE.

Bioprospecting involves the screening of biological and genetic resources for their potential use, and the development of innovative strategies for capacity building, and adding value, and the generation of resources to invest in conservation activities. Within this framework bioprospecting is carried out in collaboration with local and international research centers, universities, and the private sector. The set of criteria used by INBio, to define its research agreements, include access, equity, and transfer of technology and training. Agreements stipulate that 10 percent of research budgets and 50 percent of any future royalties be awarded to MINAE for investment in conservation, according to the Biodiversity Law of 1998. The remainder of the research budget supports in-country capacity in biotechnology and value added activities, also oriented to conservation and the sustainable use of biodiversity.

Management requirements for a successful bioprospecting enterprise, based on the INBio experience, include the following:

- Defining and implementing a bioprospecting framework, meaning favorable macropolicies, biodiversity inventories, information management systems, technology access, and business development
- Creating interdisciplinary and multidisciplinary teams of scientists, lawyers, conservation managers and business developers
- Distributing the benefits obtained from bioproducts into building biotechnology capacity and improving biological resource management.

### **Benefiting from Biodiversity**

INBio builds on sound biodiversity knowledge, which helps to define market needs, major actors,

and national scientific and technological capacities (Sittenfeld 1996; Tamayo, Nader, and Sittenfeld 1997). The principal markets for bioprospecting are the pharmaceutical, agricultural, and biotechnological sectors, with an estimated market size of over US\$600 billion worldwide (Sittenfeld, Lovejoy, and Cohen 1999). Important requirements for bioprospecting include knowledge of national and institutional strengths and weaknesses, market surveys, and evaluation of conservation needs. Most of INBio's bioprospecting activities are concentrated on the development of new pharmaceutical products; however, the basic issues and strategies can be applied to the agricultural sector as well (Sittenfeld and others 1998).

Because "raw" biological samples have low market value (Reid and others 1993), bioprospecting should seek to increase value by moving beyond simple resource collection and distribution services. Research contracts should concentrate on augmenting the value of biological resources by carrying out research in the source country. Additionally, involving in-country academics and researchers ensures that technologies transferred or accessed remain in the developing country. Increasing value is particularly important when negotiating royalty fees. In general, royalties for raw samples and collecting information are usually low, but adding information on activity, structure, and use of compounds and genes will allow increasing sharing of profits, up to 15 percent or more, depending on the area of activity and market size of the product (Reid and others 1993; Ten Kate 1995).

Guidelines provided by the Convention on Biological Diversity, and research experiences with different commercial and academic entities, allows INBio to follow basic rules such as the fair and equitable sharing of benefits, the implementation of collection methods with reduced impact on biodiversity, technology transfer, biotechnology capacity building, and up-front contribution to conservation activities. Examples of INBio agreements with academic and commercial entities are described elsewhere (Sittenfeld and Villers 1993, 1994; Sittenfeld 1996; Nader and Rojas 1996; Mateo 1996).

Recent experience in biodiversity prospecting negotiations have succeeded in establishing favorable terms for technology transfer,

royalties, and direct payments among others, for INBio, and Costa Rica's Conservation Areas. Agreements have been developed between INBio and public and academic research institutions in Costa Rica and abroad, INBio and Merck & Co. Inc., INBio and the British Technology Group/INBio and Hacienda La Pacífica, INBio and the Bristol Myers Squibb Corporation, and others. The issue of benefits accrued from bioprospecting is difficult, given the inherent complexities of assigning value to the accumulated knowledge of biodiversity, the transfer of know-how and technology, and enhanced capacity building. Up to this time products obtained from samples processed by INBio have not reached the marketplace. From 1992 to February 1998 INBio conducted bioprospecting agreements worth over US\$6 million. The use of this money can be broken down as follows: US\$3.5 million for investments and research expenses at INBio (taxonomy, information management, and biotechnology), US\$1.2 million which have been distributed to MINAE and the Conservation Areas; and US\$0.8 million to support biotechnology development at public universities. It is important to take into consideration that the figure of over US\$2.5 million for conservation and biotechnology development is significant for a country the size of Costa Rica, with a GNP of only US\$ 9 billion for 1997 (Proyecto Estado de la Nación 1998). MINAE has used its share to support the management and upkeep of Costa Rica's National Park at Coco Island, a unique site. This is a good example of direct bioprospecting benefits flowing to conservation (Mateo 1996).

The economic value of bioprospecting should not be overestimated. Bioprospecting can only complement other activities to advance human development and biodiversity conservation. Recent national policies, for example, established in Costa Rica to promote ecotourism, to protect wildlands, and to stimulate private reforestation and secondary forests, together with the promotion of reforestation programs on carbon offset for carbon fixation, produced a forest coverage of 40 percent, with an increase of 2.6 percent of secondary forest in the last year. The deforestation rate went from 22,000 hectares in 1990 to 8,000 hectares in 1994 and continues to decline (Proyecto de la Nación 1998).

## Role of the CGIAR Centers and the World Bank

Biotechnology is a necessary, but not sufficient, condition to advance social good in food and medicine. However, the CGIAR centers together with the World Bank have a pivotal role in ensuring that agricultural biotechnology impacts, in a positive way, the standard of living, food security, and poverty reduction in developing countries, by assisting these countries to take competitive effective advantage of their natural resources. Some considerations for both institutions are:

1. Establishment of system of soft loans for biotechnology development and capacity building consistent with the Kendall report (Kendall and others 1996).
2. Provide NARS with information, in particular with regular reviews of worldwide developments in the area of agricultural biotechnology and with studies of the likely impacts and appropriate developments in agricultural biotechnology for the country or the region.
3. Identification of realistic objectives and strategies for the sustainable use of biodiversity and guidance in the implementation of adequate bioprospecting frameworks.
4. Identification of opportunities to avoid or reduce negative impacts of agricultural biotechnology.
5. Promote activities to increase north/south, south/south and south/north interactions and understanding of biosafety, biodiversity conservation and national capacity development in both science and markets.
6. Development of in-house and in-country development of good quality agbiotechnology and negotiating skills, to enhance bargaining power when accessing IPR from the private sector, together with the provision by donors and CGIAR centers of licenses for enabling technologies, acquired from the private and academic sectors to NARS.
7. Promote national cooperation between national and international public and private sectors, to increase food production and

well-organized distribution systems in the country. In particular, more emphasis should be devoted to applications of biotechnology in livestock research.

8. Increase public sector biotechnology R&D on traits where the technology is not economically attractive to the private sector in the short term.
9. Promote education in key areas for agricultural biotechnology development and public awareness on biotechnology.

## References

- Brink, J.A., B. Prior, and E.J. DaSilva. 1999. Developing biotechnology around the world. *Nature Biotechnology* 17, 434-6.
- Business and Regulatory News. 1999. *Nature Biotechnology* 17, 735.
- Carter, M.H. 1996. Monsanto Company: Licensing 21<sup>st</sup> Century Technology. *Harvard Business School*. Case No.596-034.
- Delgado, C., M. Rosegrant, H. Steinfeld, G. Ehui, and C. Courbois. 1999. Livestock in 2020. The Next Food Revolution. *IFPRI/FAO/ILRI. Food, Agriculture and the Environment. Discussion Paper 28*.
- Holzman, D. 1999. Report leads to debate on benefits of transgenic corn and soybean crops. *Genetic Engineering News* 19 (8), 1 and 12.
- James, C. 1997. Progressing public-private sector partnerships in international agricultural research and development. *ISAAA Briefs* No. 4. ISAAA: Ithaca, N.Y.
- Kendall, H. (ed) 1997. Bioengineering of Crops: Report of the World Bank Panel on Transgenic Crops. Environmentally and Socially Sustainable Development Reports, The World Bank, Washington, D.C.
- Krattiger, A. 1998. The importance of ag-biotech to global prosperity. *ISAAA Briefs* No. 6. ISAAA: Ithaca, N.Y.
- Mateo, N. 1996. Wild Biodiversity: The Last Frontier? The Case of Costa Rica. In: *The Globalization of Science: The Place of Agricultural Research*. C. Bontefriedheim, and K. Sheridan (eds.). ISNAR. 73-82.
- Miller, H.I. 1999. Nasty taste from G-8 GM food policy. *Nature Biotechnology* 17, 730.
- Nader, W., and M. Rojas. 1996. Gene prospecting within the wild life. New incomes for biodiversity conservation through royalties. *Genetic Engineering News*. April.
- Nuffield Council on Bioethics. 1999. Genetically modified crops: ethical and social issues. London, Proyecto Estado de la Nación. 1998. Estado de la Nación en Desarrollo Sostenible. No.4. San José, Costa Rica.

- Reid, W.V., S. Laird, C.A. Meyer, R. Gámez, A. Sittenfeld, D.H. Janzen, M.A. Gollin, and C. Juma. 1993. *Biodiversity Prospecting: Using Genetic Resources for Sustainable Development*. Washington D.C.: World Resources Institute.
- Sasson, A. 1999. Transgenic crops. In: *Plant biotechnology-derived products: market value estimates and public acceptance*. Kluwer Academic Publishers, Dordrecht. 18-85p.
- Serageldin, I. 1999. Biotechnology and food security in the 21<sup>st</sup> century. *Science* 285,387-9.
- Simon Moffat, A. 1999. Crop engineering goes south. *Science* 285, 370-1.
- Sittenfeld, A., and R. Villers. 1994. Costa Rica's INBio: Collaborative Biodiversity Research Agreements with the Pharmaceutical Industry. Case Study 2. In G. K. Meffe, C. R. Carroll and contributors, *Principles of Conservation Biology*. Sunderland Mass: Sinauer Associates Inc.
- Sittenfeld, A. 1996. Issues and strategies for bio-prospecting. *Genetic Engineering and Biotechnology (UNIDO, Emerging Technology Series)* 4,1-12.
- Sittenfeld, A. 1998. Biotecnología, prospección de la biodiversidad y acceso a los recursos genéticos: cuestiones para América Latina.. In: Transformación de las prioridades en programas viables. Actas del Seminario de política biotecnológica agrícola para América Latina. Perú, 6 al 10 de octubre de 1996. Komen, J., C. Falconi, and H. Hernández. (eds.) La Haya/México, D.F.: Intermediary Biotechnology Service/Cambiotec.
- Sittenfeld, A., and A. Lovejoy. 1996. Biodiversity Prospecting Frameworks: The INBio Experience in Costa Rica. In press: *Their Seed Preserve: Strategies for Protecting Global Biodiversity*. McNeely and Guruswamy (eds.). Duke University Press.
- Sittenfeld, A., A. Lovejoy, and J. Cohen. 1999. Managing bioprospecting and sustainable use of biological diversity. In: *Managing Agricultural Biotechnology-Addressing Research Program Needs and Policy Implications for Developing Countries*. J. Cohen (ed.) ISNAR CAB International, UK. 92-101.
- Sittenfeld, A., and R. Villers. 1993. Exploring and preserving biodiversity in the tropics: the Costa Rican Case. *Current Opinion in Biotechnology* 4(3),280-5.
- Solleiro, J.L., and R. Castañón. 1999. Technological strategies of successful Latin American biotechnological firms. *Electronic Journal of Biotechnology* 2, 26-35.
- Spillane, C. 1999. Commission on Genetic Resources for Food and Agriculture. Recent developments in biotechnology as they relate to plant genetic resources for food and agriculture. FAO. Background Study Paper No. 9.
- Tamayo, G., W.F. Nader, and A. Sittenfeld. 1997. Biodiversity for the Bioindustries. In *Biotechnology and Plant Genetic Resources: Conservation and Use*. B.V. Ford-Lloyd, H.J. Newbury, and J.A. Callow (eds.). Wallingford, Oxon, England: CAB International.
- Thayer, A.M. 1998. Living and loving life sciences. *Chemical & Engineering News* 76(47), 17-24.
- Thayer, A.M. 1999. Transforming agriculture. *Chemical and Engineering News* July 19, 21-35
- Ten Kate, K. 1995. Biopiracy or green petroleum? Expectations and Best Practice in Bioprospecting. Overseas Development and Administration (ODA), London.
- Varley, J.D., and P.T. Scott. 1998. Conservation of Microbial Diversity a Yellowstone Priority. *ASM News* 64, 147-51.