International Activities on the Development and Transfer of Biotechnology for Developing Countries

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Abstract

A growing range of international agricultural biotechnology expertise exists which seeks to address the challenges posed concerning the transfer of biotechnology to developing countries. This expertise is composed of research programs, advisory programs, bilateral or multilateral donor agencies, and regional or international biotechnology networks. Taken together, they constitute an important source of support and collaboration for developing countries planning or implementing biotechnology. However, products from this research also create challenges for decision makers, research scientists, and the public in developing countries regarding their development, transfer and safe use. As part of their approach, a number of these international initiatives include support for both biosafety and the efficacy of research. This paper will begin by summarizing information contained in a database specifically designed by the Intermediary Biotechnology Service to examine the relation between these internationally supported activities and the needs and capabilities of the national agricultural research programs in developing countries. Following a review of these international activities and their research objectives, the challenges and opportunities which they pose to the developing countries will be explored. The paper will close by summarizing ways to help maximize returns expected from international collaboration, and ways to manage the needs for both efficacy and safety while undertaking research for and with developing countries.

Introduction

Applications of biotechnology provide for more productive use of biological and genetic resources in developing country agricultural systems. Additionally, biotechnology's set of tools offer the opportunity for more efficient and specific modification of plant, animal and microbe genomes. However, these tools must be advanced as part of the agricultural research continuum, closely linked to a conventional agricultural research "foundation"in order to move results from laboratory to the field. In the context of the integration of agricultural biotechnology into conventional breeding, Day (1993) has identified the following areas of practical accomplishments from biotechnology:
(1) Transformation, gene isolation and cloning;

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(2) Mapping and marker-assisted selection;
(3) Micropropagation and tissue culture;
(4) Hybrid seed production;
(5) Control of gene expression.

Rapid developments in the above-mentioned areas are prompting developing country governments to initiate either national programs or to stimulate new research projects for agricultural biotechnology. Growing numbers of governments are making investments in infrastructure and human resources to support this research, and are adopting policies to facilitate biotechnology R&D in both the public and private sectors. Linking applications of the above-mentioned technologies to specific agricultural needs and objectives is a challenge faced by decision makers and researchers in developing countries.

The international donor community is addressing this challenge by supporting a range of collaborative activities in agricultural biotechnology, through international biotechnology research and advisory programs and through regional and international networks. Collaborating with these initiatives provides developing country scientists and policy makers with opportunities to benefit from the knowledge and information gained regarding specific technologies and their applications; biosafety and technology transfer issues, and broader policy and planning implications for national research systems. This paper will examine information, obtained by the Intermediary Biotechnology Service (IBS), a special project initiated by the International Service for National Agricultural Research (ISNAR), which describes identified international biotechnology research and advisory programs, and looks at the needs and opportunities for the development and transfer of products from their research to be utilized by developing countries.

BioServe, a directory of expertise

During the past decade, the international donor community has increasingly become involved in supporting collaborative activities in agricultural biotechnology. To better understand emerging needs of developing countries regarding collaboration with international research and advisory programs, a meeting was organized by IBS in November 1993 and held at ISNAR, in The Hague, The Netherlands (Cohen and Komen, 1994). For this conference, information was collected from approximately 40 international initiatives in agricultural biotechnology. These initiatives were categorized as follows:

- Research programs for crops or livestock at national or international public institutes;
- Advisory programs which concentrate on policy and research management issues;
- International or regional biotechnology networks for specific crops or regions;
- Bilateral or multilateral donor programs which support international biotechnology

activities.

Information was collected first from identified international programs as they can be primary providers of technology, information and collaboration for national programs in developing countries. Three different survey forms were designed for the identified programs, networks, and donor agencies, that requested information on: 1) general logistical information and overall goals and priorities; 2) agricultural research focus in terms of crops, livestock species, livestock diseases, or other; 3) regional focus and collaborating institutes from developed and developing countries; 4) type, number and location of training opportunities provided; 5) activities and methods developed in program planning, policy and management; 6) information products and services; 7) support for infrastructure development in developing country programs; 8) research and development projects, their status, and technology transfer channels; and, 9) funding sources and expenditures.

The individual profiles obtained from the survey were published first as a directory (IBS, 1994) which is now being updated, and will be followed by electronic and Internet dissemination. In addition, aggregate data from BioServe were used in an analysis of these initiatives in a report published by the OECD Development Centre (Brenner and Komen, 1994).

Table 1 provides a full overview of organizations and initiatives included in the IBS survey. Although they vary widely in scope and content, each of these programs aims to facilitate developing countries' access to modern agricultural biotechnology.

In the remainder of this paper, we concentrate on the research programs included in the data base. Most of the research programs focus on crop-related research (see Table 1), including those based at international agricultural research centers. In addition, the networks covered by the survey also primarily work on biotechnology applied to crops. Crop research is the most prominent aspect of the international programs, which incorporate accomplishments within the five main biotechnology areas identified by Day (1993). Specifically with regard to crop transformation, Table 2 presents nine general categories of application and specific examples of objectives within these categories. The second column primarily summarizes research being conducted in industrialized countries. To compare this information with current research focusing on developing country agriculture, the third column provides examples of research objectives targeted by international programs. As can be seen, research in the international programs concentrates particularly on plant resistance to viruses and insects.

Products from international collaboration: expectations for technology transfer

For a growing number of developing countries, collaborating in international research programs for agricultural biotechnology offers a range of opportunities for acquiring access to specific technologies and training programs. The overall geographic focus of the international biotechnology programs is more or less evenly spread among the different regions. While a relatively large number of developing countries are involved, efforts are concentrated in a small number of countries within each geographic region. Table 3 gives examples of collaborative crop and livestock projects in agricultural biotechnology in which Southeast Asian institutions are participating. Most activities to date are concentrated in Indonesia, The Philippines and Thailand, all countries with relatively high levels of scientific and technological capability.

In these countries, decisions regarding how to organize the development and diffusion of biotechnology products should be made early-on. Presently, biotechnology research among developing countries is primarily the responsibility of the public sector, often leaving the conventional agricultural research system as the only conduit for product delivery. However, the commercial sector can also play an important role, depending on the clients, agroservices, and the technology transfer routes available. Regardless of whether distribution is done by the public or private sector, recognized routes for technology transfer must be established. Even though researchers themselves may not be responsible for technology transfer, the directors of biotechnology research do have responsibility for their outputs reaching end users.

There are multiple methods for transferring technology into and within developing country agricultural research institutes. As identified in the IBS analysis of international biotechnology programs, technology transfer opportunities for biotechnology include the following:

- public sector (NARS and other government institutions);
- IARCs, which release material through international testing programs;
- non-profit institutions such as universities; and
- commercial organizations.

As shown in Fig.1, the largest effort is expected to occur through the public sector, as most applications of biotechnology supported through the international donor community target crops or production systems traditionally serviced by national extension and research programs. Crops such as rice, beans, potato, sweet potato, and cassava, for example, are often planted from seed or planting material saved by farmers. Incentives for large scale private sector investment are therefore lacking. For these crops, improved planting materials distributed by IARCs, universities, or other international programs will have to be registered for release by each developing country and this is primarily a public sector responsibility.

In this regard, national and public institutions also benefit from collaboration with international biotechnology programs. The international programs provide access to

both public and proprietary-domain technologies. Examples of commercial technology transfer originating from these international programs are shown in Table 4. These new opportunities build on the traditional collaboration of IARCs and developing country NARS with public sector institutions in developed countries for advances in basic research

Technology transfer and product development, national perspectives from Southeast Asia

To respond to the issues and options for technology transfer associated with biotechnology, and because of the importance of these issues in the Southeast Asian region, representatives of six countries in Southeast Asia attended the first in a series of *Agricultural Biotechnology Policy Seminars*,. titled, Turning Priorities into Feasible Programs: Regional Seminar on Planning, Priorities, and Policies for Agricultural Biotechnology. The seminar was held in Singapore, September 25-29, 1994, and was designed and organized by the Intermediary Biotechnology Service (Komen, Cohen and Lee, 1995). Each seminar is designed to strengthen the capacity of developing countries to plan and manage agricultural biotechnology, and to help turn research priorities into realistic programs.

The seminar had six topical sessions in total, one of which was devoted to technology transfer and titled, *Delivering Benefits : Technology Transfer and End Users*. Three case studies were used to illustrate technology transfer mechanisms, their relation to national policies, and various routes of delivery. An overview presentation was provided by the OECD Development Centre, summarizing incentives and disincentives to technology transfer synthesized from commissioned country studies. The plenary session was followed by participant action planning undertaken in six national working groups, including Indonesia, Malaysia, The Philippines, Singapore, Thailand and Vietnam.

Needs identified in the national working groups focusing on technology transfer included those for technology transfer in general, and other needs specific to biotechnology. The groups recognized that new modalities and policies are needed to optimize research efforts targeting commercially viable products. Policies are especially needed for stimulating public-private collaboration, the transfer of public innovations for commercial production, and for stimulating investment in agricultural development. New modalities are needed for better market identification, closer links to end users, and, new or better options regarding technology transfer.

For agricultural biotechnology, much work remains to build effective competence in public and private research, and to determine ways to work in conjunction with one another. Each national delegation at the seminar included a representative from the national commercial sector in order to stimulate discussions with those representing national public agricultural research. Government institutions were requested to consider the following actions to stimulate product development:

1. Establishing clear policy regulations with regard to product price, quality and registration;
2. Offering on-farm demonstrations and pilot-scale production facilities; and,
3. Procuring and distributing micro-propagated planting material.

Country-specific needs included the improvement of research-extension linkages to strengthen the technology transfer system for Indonesia. Malaysia identified a lack of contact between R&D institutions and end users. The Philippines recognized that incentives are insufficient for bioindustries, and greater promotion of results is needed for small scale farmers. Singapore stressed greater need to understand the affordability of new technologies, and to devise methods ensuring cost consciousness when planning research. Thailand recognized its weak coordination in the transfer of technology, and would like to enhance participation of government and private organizations. Vietnam emphasized the need for quality control and reinforced its call for pilot demonstrations in diverse areas of the country.

Products from biotechnology: biosafety implications

Policy makers in countries where biotechnology research is conducted, and the products of genetic engineering are developed, tested, imported, exported or used, should develop a biosafety regulatory structure. First, the presence of an effective biosafety system can become a condition for international collaboration. Donor-funded, international collaborative research programs often contain specific requirements for biosafety. Secondly, an increasing number of national institutions are already set to release transgenic organisms into the environment. This has created an immediate need to establish biosafety structures, in order to encourage progress in national research,

As shown in Table 3, a wide range of collaborative biotechnology projects are underway in Southeast Asia. Some of these projects do not require specific provisions with regard to biosafety, such as those involving mass propagation and diagnostics. However, quite a number of projects will eventually yield genetically engineered crop varieties, e.g, insect-resistant rice, which generally require consideration with regard to biosafety regulations for laboratory work, greenhouse tests, field trials, and, eventually, consumer safety assessment. To date, the number of actual field trials in Southeast Asian countries is very low, with only two that have taken place in Thailand (for transgenic tomato). However, if success rates leading to field trials are similar for the international program efforts as they have been in the industrialized countries, then the number of applications for field trials in tropical countries will increase drastically.

Summary and conclusion

In the early 1980s, representatives of the international donor and development community began to consider their options regarding biotechnology and its potential use in helping to meet the food and agricultural needs of developing countries. The international community has now responded to these needs, primarily through the support and financing provided to the range of international initiatives. This first aggregate look at these initiatives focuses on the period of 1985-1995, which has been a period of dynamic growth for these initiatives.

In the coming decade, these initiatives, and those who sponsor, collaborate and finance them, will be interested in determining the impact of their research and advisory services, and if they have successfully delivered their products to the developing countries. With regard to many of the expected products, this delivery will depend on each project's ability to satisfy biosafety and regulatory hurdles in the developing countries, while at the same time presenting products which offer clear improvements over existing technologies or other agricultural alternatives.

Data presented in this paper indicate that developing countries, such as those mentioned in Southeast Asia, are recognizing the challenges which the transfer of these technologies and products mean to their national research system, and are beginning to take measures to address these challenges. Similar efforts are needed to help the international biotechnology research and advisory programs, in order to ensure that products from collaborative research reach the developing counties. Working together on the most promising technological developments will help identify and find support for the longer-term needs of product development, that is, the necessary work which comes after basic research has been completed.

Collaborating with these international research and advisory programs over the next decade offers one way to effect the development of new technologies, and the opportunity to identify further steps and associations needed for the safe transfer of these new technologies to developing countries. Identifying what conditions have led to successful examples in this regard will be the key not only to determining impact, but for ensuring the continuity of these international biotechnology efforts long enough to effect the transfer of safe and efficacious agricultural products.

References

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Table 1 Summary of international agricultural biotechnology initiatives

NAME (host institution)	PRIORITIES	AGRICULTURAL FOCUS (crop/livestock)	REGION/ COUNTRY FOCUS
CROP RESEARCH PROGRAMS			
Agricultural Biotechnology for Sustainable Productivity, ABSP (Michigan State University, USA)	· genetic engineering of crops for pest/disease resistance · development of micropropagation systems · integration of biotechnology within a general agriculture and business framework	· maize · potato · coffee · sweet potato · horticultural crops	· Indonesia · Egypt · Costa Rica · Kenya
Bean/Cowpea Collaborative Research Support Program, B/C CRSP (various US universities)	· control of pests and diseases · increase crop yields · increase nutritional quality	· bean · cowpea	· international
Center for the Application of Molecular Biology to International Agriculture, CAMBIA	· novel biotechnologies and methods for agricultural innovation · genetic markers and diagnostics · apomixis	· rice · cassava · bean · agroforestry	· international
CATIE - Biotechnology Research Unit (Centro Agronomico Tropical de Investigacion y Ensenanza, Costa Rica)	· enhance regional program capabilities · genetic improvement of tropical crops	· Banana/plantains · coffee · cocoa · roots and tubers	· Latin America and the Carribean
CIRAD - Plant Breeding Division (Centre de coopération international en recherche agronomique le développement, France)	· develop genetically improved crops	· cotton · rice · sorghum · tropical perennials · tropical fruits · forestry	· international
Feathery Mottle Virus Resistant Sweet Potato for African Farmers (Agency for International Development, USA)	· human resource development · production of virus-resistant, African varieties of sweet potato · enhance capacity in biosafety regulation of transgenic crop plants · export of transgenic sweet potato to Africa for field testing · technology transfer	· sweet potato	· Kenya

NAME (host institution)	PRIORITIES	AGRICULTURAL FOCUS (crop/livestock)	REGION/ COUNTRY FOCUS
ICGEB - Plant Biotechnology Sub-Programme (International Center for Genetic Engineering and Biotechnology, Italy/India)	· capacity building · genetically improved rice	· rice	· international
IIRSDA - Plant Biotechnology Program (Institut internatioanl de recherche scientifique pour le devélopment en Afrique, Côte d'Ivoire)	· conservation and characterization of yam germplasm · micropropagation and genetic improvement of yam and other crops	· yam · African eggplant	· Africa
International Laboratory for Tropical Agricultural Biotechnology, ILTAB (Scripps Research Institute, USA)	· genetically engineered food crops with virus resistance	· rice · cassava · tomato · sugarcane	· international
International Program on Rice Biotechnology (Rockefeller Foundation, USA)	· rice genetic improvement · capacity building	· rice	· international
International Service for the Acquisition of Agri-biotech Applications, ISAAA (Cornell University, USA)	· acquisition and transfer of near-term applications of agricultural biotechnology applications, particularly proprietary technology · biosafety	· vegetables · fruits · field crops · agroforestry	· international
Overseas Development Administration - Plant Sciences Research Programme (University of Wales, UK)	· genetically improved crops	· cereals · roots and tubers · legumes · oilseeds · fruit and vegetables · fibres	· international
Regional Program of Biotechnology for Latin America and the Caribbean (several UN organizations)	· collaborative research projects · training	· maize · potato · sugarcane	· Latin America and the Caribbean
Research on the Date Palm and the Arid Land Farming Systems	· in-vitro propagation · biological control technology · date palm farming systems	· date palm	· Africa · Asia

NAME (host institution)	PRIORITIES	AGRICULTURAL FOCUS (crop/livestock)	REGION/ COUNTRY FOCUS
LIVESTOCK RESEARCH PROGRAMS			
CIRAD - Animal Production Division (Centre de coopération international en recherche agronomique pour le développement, France)	· development of heat-stable vaccines through genetic engineering · improved diagnostic tests · determination of genetic resistance to diseases	· cowdriosis · dermatophilosis · rinderpest · peste des petits ruminants · mycoplasmosis · trypanosomiasis	· international
International Laboratory of Molecular Biology for Tropical Disease Agents, ILMB (University of California, USA)	· live recombinant virus vaccines for animal diseases · technology transfer	· rinderpest · bovine virus diarrhea · equine influenze · peste des petits ruminants · foot and mouth disease · vesicular stomatitis virus	· international
Indo-Swiss Collaboration in Biotechnology, ISCB (Federal Institute of Technology, Switzerland)	· capacity building · animal disease diagnostics and vaccines · biopesticides	· foot and mouth disease · contagious caprine pleuropneumonia	· India
Small Ruminant Collaborative Research Support Program - Animal Health Component (Washington State University, USA)	· improve the efficiency of milk and meat production from small ruminants · virus-vectored vaccines for sheep and goats	· heartwater · contagious caprine pleuropneumonia · Nairobi sheep disease	· Kenya · Indonesia · Bolivia
Tickborne Diseases Vaccine Development Program (University of Florida, USA)	· development and commercialization of improved vaccines and diagnostic tests	· heartwater · anaplasmosis · babesiosis	· international
IARC-BASED BIOTECHNOLOGY PROGRAMS			
Biotechnology-Assisted Breeding to Reduce Pesticide Use in Potatoes (International Potato Center, Peru)	· durable resistance to pests and diseases · integrated pest management	· potato	· International
CIAT - Biotechnology Research Unit (International Center for Tropical Agriculture, Colombia)	· increasing the efficiency of CIAT strategic research · institutional development in biotechnology	· cassava · common bean · rice · tropical forages	· international

NAME (host institution)	PRIORITIES	AGRICULTURAL FOCUS (crop/livestock)	REGION/ COUNTRY FOCUS
ICIPE - Biotechnology Research Unit (International Center of Insect Physiology and Ecology, Kenya)	· biological control of pests (plant protection) and vectors · development of anti-tick vaccines · development of diagnostics tools	· maize · sorghum · cowpea · cattle	· Africa
ICRISAT - Molecular and Cellular Biology Program (International Crops Research Institute for the Semi-Arid Tropics, India)	· support and complement conventional crop improvement programs at ICRISAT	· sorghum · pearl millet · groundnut · chickpea · pigeonpea	· international
IITA - Biotechnology Research Unit (International Institute for Tropical Agriculture, Nigeria)	· tackle recalcitrant problems in crop improvement · enhance national research capabilities	· cowpea · yam · cassava · banana/plantain	· Africa
Reducing Maize Losses to Insect Pests by Enhancing Host Plant Resistance with *Bacillus thuringiensis* Toxin Genes (International Center for Maize and Wheat Improvement, Mexico)	· enhanced insect resistance maize germplasm	· maize	· international
ILRI - Tick-Borne Diseases Program (International Livestock Research Institute, Kenya)	· novel vaccines · improve current control methods	· theileriosis · cowdriosis · anaplasmosis · babesiosis	· international
ILRI - Trypanosomiasis Program (International Livestock Research Institute, Kenya)	· improve diagnosis and parasite characterization · novel vaccines · breeding for genetic resistance	· trypanosomiasis	· international
ADVISORY PROGRAMS			
Biotechnology Advisory Commission, BAC (Stockholm Environment Institute, Sweden)	· review biotechnology projects involving field testing and/or the planned introduction of genetically modified organisms		· international

NAME (host institution)	PRIORITIES	AGRICULTURAL FOCUS (crop/livestock)	REGION/ COUNTRY FOCUS
Canada-Latin America Initiative on Biotechnology and Sustainable Development, CamBio Tec (International Development Research Centre, Canada)	· identify opportunities for biotechnology research and application by tracking technological trends and carrying out priority-setting exercises · strengthen public policies in biotechnology · promote improved management of innovations · foster partnerships between Canadians and Latin Americans		· Latin America
Intermediary Biotechnology Service, IBS (International Service for National Agricultural Research, The Netherlands)	· biotechnology research program management and policy formulation · country reviews · identify international program expertise		· international
Support to Agricultural Biotechnology Policies (Interamerican Institute for Cooperation in Agriculture, Costa Rica)	· biosafety, IPR · industry development		Latin America and the Caribbean
NETWORKS			
African Biosciences Network - Sub-Network for Biotechnology, ABN-BIOTECHNET (University of Nigeria, Nigeria)	· genetically improved crops and farm animals · disease control through new vaccines · capacity building		· Africa
Asia Network for Small-Scale Agricultural Biotechnologies, ANSAB	· plant tissue culture · biopesticides · biofertilizers · mushroom technology	· potato · kapok tree · rice · mushroom	· Asia
Asian Rice Biotechnology Network, ARBN (International Rice Research Institute, The Philippines)	· DNA fingerprinting of pests and pathogens · low-cost marker-aided selection · transgenic rice	· rice	· Asia
Phaseolus Bean Advanced Biotechnology Research Network, BARN (International Center for Tropical Agriculture, Colombia)	· constraint identification · technology transfer · information exchange	· beans	· international
Cassava Biotechnology Network, CBN (International Center for Tropical Agriculture, Colombia)	· stimulate cassava biotechnology research on priority topics · integrate priorities of small-scale farmers, processors, and consumers in cassava biotechnology research planning · information exchange	· cassava	· international

NAME (host institution)	PRIORITIES	AGRICULTURAL FOCUS (crop/livestock)	REGION/ COUNTRY FOCUS
Technical Cooperation Network on Plant Biotechnology, REDBIO (Food and Agriculture Organization of the United Nations, Regional Office for Latin America and the Caribbean, Chile)	· generation, transfer and application of plant biotechnology · national and regional policies · information exchange	· vegetables · roots and tubers · cereals	· Latin America and the Caribbean
DONOR AGENCIES			
Australian Center for International Agriculture Research, ACIAR	· use biotechnology wherever appropriate as a research tool within any of ACIAR's projects		· international
DGIS Special Programme Biotechnology and Development Cooperation (Ministry of Foreign Affairs, The Netherlands)	· improve developing country access to biotechnology, with special emphasis on small-scale producers and women · technical cooperation · international collaboration and coordination	· "orphan" commodities · cassava	· Colombia · India · Kenya · Zimbabwe
FAO/AGP Programme on Plant Biotechnology (Food and Agriculture Organization of the United Nations, Italy)	· information dissemination and cooperation · advisory services · capacity building · promote research, technology transfer and adoption	· rice · roots and tubers · horticulture · industrial crops	· international
Swedish Agency for Research Collaboration with the Developing Countries, SAREC	· plant and forestry genetics · diagnositcs and vaccines in veterinary medicine · environment · biosafety · policy research		· Africa · Asia
United Nations Development Programme (USA)	· productive and sustainable agriculture	· food crops · cash crops · livestock	· international
World Bank (USA)	· invest in biotechnology as a contribution to economic development in World Bank member countries		· international

Table 2 Cloned genes of interest for crop plant improvement and application of international biotechnology programs

General Category	Specific Examples[1]	International Biotechnology Program Application [2]
Disease resistance: viruses	· Virus coat protein subunits (TMV, cucumber mosaic, potato virus X) · Potato leaf roll virus · Potato virus S · Soil-borne wheat mosaic virus · Plum pox virus · Tomato spotted wilt virus · Viral replicase gene (PVX)	· African cassava mosaic virus, common cassava mosaic virus · bean gemini viruses · rice stripe virus, yellow mottle virus, tungro virus, ragged stunt · potato virus X and Y · tomato yellow leaf curl virus · sweet potato feathery mottle virus · groundnut stripe virus, Rosette virus, and clump virus
Fungal diseases	Chitinase gene, H1 gene for resistance to H. *carbonum* from maize, systemin gene - a peptide signal molecule which controls would reponse in plants, infectious viral cDNA	· potato late blight · rice blast
Insect resistance	*B.t.* genes, cowpea trypsin inhibitor, wheat agglutinin gene for resistance to European corn borer	· *B.t.* toxin gene applied to borers in maize, rice, sugarcane, potato, coffee · potato glandular trichomes · sweet potato weevil · pigeonpea: Helicoverpa and podfly
Storage protein genes	Wheat low molecular weight glutenin gene, maize storage protein	no applications reported
Carbohydrate products	Polyhydroxybutyrate as an alternative to starch for the production of biodegradable plastics	no applications reported
Ripening	Antisense polygalacturonase in tomato, regulation of ACC synthase gene	no applications reported
Breeding systems	Self-incompatibility genes from *Brassica*, anther specific genes used for male sterility with a ribonuclease gene	· male sterility in rice
Flower color	Petunia, Antirrhinum	no applications reported
Herbicide resistance	Glyphosate, bialaphos and, imidazolinone resistance	no applications reported

[1] General categories and specific examples cited from Day, 1993.
[2] Examples from IBS BioServe data base of international agricultural biotechnology programs.

Table 3 Collaboration in research-Southeast Asia

COUNTRY	R&D CATEGORY	R&D ACTIVITY	PROGRAM
Indonesia	Animal health	Evaluation of antigens for vaccination against liver fluke in cattle and buffalo	ACIAR
	Crop productivity	Micropropagation of pineapple	ABSP
		Hybrid rice, engineered male sterility	RF
	Crop protection	Genetic engineering of sweet potato for insect resistance	ABSP
		Genetic engineering of maize for resistance to Asian corn borer	ABSP
		Genetic engineering of potato for resistance to potato tuber moth	ABSP
		Control of bacterial wilt through *Pseudomonas solanacearum*	ACIAR
		Developing genetically engineered commercial peanut cultivars with resistance against peanut stripe virus	ACIAR
		Mapping rice genes for resistance to pests and diseases	ARBN
		DNA fingerprinting of rice pests and diseases	ARBN
		Rice insect resistance, *B.t.* toxin gene for stemborers	RF
	General technology development	Bioreactor technology	ABSP
		Cloning *Bt* toxin genes from new strains	ABSP
		Regeneration systems for maize and potato	ABSP
		Low-cost technology for marker-aided selection	ARBN
		Cytoplasmic male sterility for biosafety	ARBN
		Zygotic embryo coconut storage	CIRAD-MICAP
		Oilpalm somatic embryogenesis	CIRAD-MICAP
		Coconut somatic embryogenesis	CIRAD-MICAP
		Rice transformation and regeneration	ILTAB
		Rice pathogen and pest molecular maps	RF
		Rice molecular map	RF
Malaysia	Crop productivity	Micropropagation of rattan and tropical forest species	ISAAA
	Crop protection	Rice transformation for resistance to stripe virus	RF
		Rice transformation for resistance to ragged stunt virus	RF
		Rice transformation for resistance to yellow mottle virus	RF
		Rice transformation for resistance to tungro virus	RF
	General technology development	Genome mapping of rubber	CIRAD-MICAP
		Oilpalm somatic embryogenesis	CIRAD-MICAP
		Coconut somatic embryogenesis	CIRAD-MICAP
		Rice transformation and regeneration	ILTAB

Philippines	Crop productivity	Micropropagation of rattan and tropical forest species	ISAAA
	Crop protection	Control of bacterial wilt through *Pseudomonas solanacearum*	ACIAR
		Introduce resistance to papaya ringspot virus into commercial papaya, using in vitro embryo culture	ACIAR
		Mapping rice genes for resistance to pests and diseases	ARBN
		DNA fingerprinting of rice pests and diseases	ARBN
		Rice transformation for resistance to stripe virus	RF
		Rice transformation for resistance to ragged stunt virus	RF
		Rice transformation for resistance to yellow mottle virus	RF
		Rice insect resistance, *B.t.* toxin gene for stemborers	RF
		Rice transformation for resistance to tungro virus	RF
	General technology development	Low-cost technology for marker-aided selection	ARBN
		Cytoplasmic male sterility for biosafety	ARBN
		Rice transfrmation and regeneration	ILTAB
		Rice transfrmation	RF
		Rice pathogen and pest molecular maps	RF
		Rice molecular map	RF
Singapore	Crop productivity	Nitrogen-fixation studies in acacia and casuarina	CIRAD-MICAP
Thailand	Animal health	Diagnostics for anaplasmosis	TDV
		Recombinant vaccine for anaplasmosis	TDV
	Crop productivity	Micropropagation of rattan and tropical forest species	ISAAA
		Hybrid rice, engineered male sterility	RF
	Crop protection	Transgenic rice with enhanced resistance	ARBN
		Mapping rice genes for resistance to pests and diseases	ARBN
		Insect-resistant cotton through the transfer of *B.t.* toxin genes or protease inhibitor genes	CIRAD-MICAP
		Rice transformation for resistance to stripe virus	RF
		Rice transformation for resistance to ragged stunt virus	RF
		Rice transformation for resistance to yellow mottle virus	RF
		Rice insect resistance, *B.t.* toxin gene for stemborers	RF
		Rice transformation for resistance to tungro virus	RF
	General technology development	Physiology of latex production	CIRAD-MICAP
		Rice pathogen and pest molecular maps	RF
		Rice molecular map	RF

Vietnam	General technology development	Zygotic embryo coconut storage	CIRAD-MICAP
		Genetic transformation of acacia through *Agrobacterium*	CIRAD-MICAP
		Genetic transformation of acacia and casuarina through particle gun	CIRAD-MICAP
		Coconut somatic embryogenesis	CIRAD-MICAP
		Rice molecular map	RF

ABSP = Agricultural Biotechnology for Sustainable Productivity; ACIAR = Australian Centre for International Agricultural Research; ARBN = Asia Rice Biotechnology Network; CIRAD-MICAP = Centre de coopération internationale en recherche agronomique pour le développement - Plant Breeding Division; ILTAB = International Laboratory for Tropical Agricultural Biotechnology; ISAAA = International Service for the Acquisition of Agri-Biotech Applications; RF = Rockefeller Foundation International Rice Biotechnology Program; TDV = Tickborne Diseases Vaccine Program

Source: IBS BioServe data base

Table 4 Private sector technology transfer in international research programs on agricultural biotechnology

International Program	Private sector Collaborator	Technology	Collaborating Institute(s)
Agricultural Biotechnology for Sustainable Productivity (ABSP)	ICI Seeds (USA)	Maize transformation with *Bacillus thuringiensis* protein genes, for resistance to Asian stemborer	Central Research Institute for Food Crops (CRIFC, Indonesia)
	DNA Plant Technology (USA)	Bioreactor technology for micropropagation of banana, pineapple, coffee, and ornamental palms	· Agribiotecnologia de Costa Rica (ACR) · Fitotek Unggul (Indonesia)
Feathery Mottle Virus Resistant Sweet Potato for African Farmers	Monsanto (USA)	Transformation technology for the development of virus-resistant sweet potato	Kenya Agricultural Research Institute (KARI)
International Service for the Acquisition of Agribiotech Applications (ISAAA)	Monsanto (USA)	Transformation technology for the development of potatoes resistant to potato virus X and Y	Center for Advanced Research Studies (CINVESTAV, Mexico)
	Agrow Seed (USA)	Coat-protein technology for the development ofmelons resistant to-cucumber mosaic virus	· Research Center in Cell and Molecular Biology (CIBCM, Costa Rica) · CINVESTAV
	Pioneer Hi-Bred (USA)	ELISA kits for local maize viruses	National Research Center for Maize and Sorghum (CNPMS, Brazil)
ODA Plant Sciences Research Programme	Agricultural Genetics Company (UK)	Insect resistance genes for potato and sweet potato	International Potato Center (CIP, Peru)

Source: IBS BioServe data base

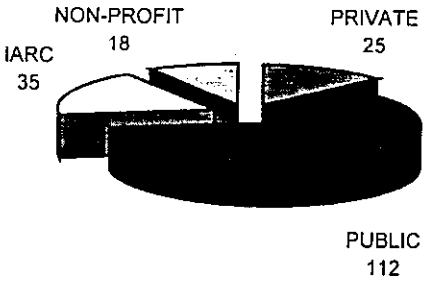

Fig.1 Technology transfer routes
(no. of projects analyzed=190)