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National Agricultural Biotechnology Research Capacity in Developing Countries

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Abstract

Adequate public research capacity is key to the appropriate development of biotechnology, including genetically modified (GM) crops. While commercial crops can be introduced without intensive local research (i.e. insect resistant GM cotton), introducing products of public research depend on indigenous capacity. This paper defines capacity for agricultural biotechnology research and then provides national funding levels for such work in six developing countries. As one indicator of capacity and outputs, GM crops developed from public research in developing countries are documented, and attention given to issues remaining for capacity, research and development. Knowledge of investments in public biotechnology improves policy decisions, clarifies roles of the public and private sectors, and supports public-sector implementation of research. The paper concludes with conclusions and implications based on the investment and GM crop research data presented.

Key Words: Biotechnology, Research Capacity, GMO, Biosafety, Investments, Funding.

JEL: O31, O38, Q16.

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National Agricultural Biotechnology Research Capacity in Developing Countries

Background paper for FAO's State of Food and Agriculture

1. INTRODUCTION

A critical determinant of the availability and accessibility of biotechnology innovations in developing countries is the countries' own national capacity in biotechnology research. National research capacity increases the ability to import and adapt agricultural technologies, to ensure that the public goods aspects of research are addressed (e.g. 'orphan crops'), and to appropriately regulate technologies. In this paper, we will focus on reviewing the status of agricultural biotechnology research capacity and on public sector GM crop development in selected developing countries (agriculture includes crops, livestock, fisheries and forestry).

Poor rural producers in developing countries depend directly or indirectly on productivity increases in agriculture to rise above poverty. Early evidence on farm-level impacts confirms that biotechnology applications may help poor farmers increase their productivity. Such products best arise when research is focused on smallholder problems, undertaken together with research to improve agronomic practices, and its deployment as a component of prudent and comprehensive development policies including improved access to markets.

The levels of financial and human investments made in agricultural biotechnology research are two indicators of national commitment to create or strengthen national biotechnology capacities. Knowledge of these investments in public agricultural biotechnology research is needed to improve policy decisions, clarify roles of the public and private sectors, and support public-sector implementation of biotechnology research. However, very little comprehensive and consistent data on resources for agricultural biotechnology exists to allow comparisons between countries and from which to draw valid research policy recommendations.

2. DEFINING RESEARCH CAPACITY

We define research capacity, as the portfolio of resources – physical, human, and financial –available in a research system for performing and utilizing research. Research capacity is not limited to undertaking research projects alone, but includes engagement with a broader innovation system, including specifying, accessing, interpreting and applying research. For agricultural biotechnology, research capacity also involves a spectrum of key elements and activities, including:

- Defining objectives and priorities for agricultural biotechnology;
- Developing and implementing a clear policy for (agricultural) biotechnology, and biosafety regulations;
- Developing R&D management capacity;

- Transfer of technologies, knowledge and skills to the private sector;
- Promoting international collaboration and technology transfer.

(Janssen, Falconi and Komen, 2000)

How such research capacity creates outcomes requires a broader discussion of approaches and methods. With the involvement of stakeholders comes new research objectives for public sector institutions. The tendency now is for research systems to develop capacity that is flexible, rigorous and which actively involve a wider range of stakeholders. This includes approaches taking into account social and economic considerations, and other approaches allowing public research systems to address environmental and biodiversity concerns, resource degradation, public health issues such as HIV/AIDS, and other critical problems affecting agriculture.

2.1 Unique challenges in agricultural biotechnology

Capacity building in agricultural biotechnology faces unique challenges when compared to other technological revolutions, including the Green Revolution in the 1950s and 1960s. These challenges, either directly or indirectly, affects capacity building, retention of personnel, and the balance between public and private sector capabilities. These challenges include:

High development costs

Whether a country is an innovator in agricultural biotechnology, or whether it adapts technology developed elsewhere, getting involved will entail new investments in research infrastructure (including, for example, contained greenhouses), tax breaks or subsidies for pioneering companies, training and management development for research institute personnel.

Integration and competition with conventional research programs

There is a concern that resources devoted to germplasm conservation and enhancement as well as conventional plant breeding activities may be re-directed towards biotechnology research.

Corporate control, market power, and distributional implications

Private sector companies have primarily researched, developed and marketed biotechnology products. This is a departure from the “Green Revolution” technologies of the 1950s and 1960s, such as semi-dwarf varieties of wheat, developed primarily by the public sector. Initially, the private sector held exclusive ownership of biotechnology innovations. This opened the possibility for private sector companies to exercise market power in the seed (and other input) markets¹. Economist’s wariness about this issue is a result of concentrated market structures being associated with above normal prices and extraction of rents from producers who buy inputs. In the specific case of seed markets,

¹ The need to provide incentives for adopting the innovation, the availability of technological alternatives, and the potential entry of potential competitors who may see abnormal profits as a sign for potential lines of business may limit the amount charged over the competitive price by the innovator.

some authors (e.g., Kloppenburg 1988) propose that seed prices are already higher than normal, and that the long-term goals of enhancing germplasm and improving genetic diversity have suffered with increases in market concentration.²

Intellectual property issues

An expanding body of literature shows that increasingly both private firms and public institutions claim property rights in agricultural research and biotechnology. Property rights instruments include patent rights; plant variety rights; and contractual rights arising from material transfer agreements (MTAs). The strengthening and enforcement of intellectual property rights (IPRs) throughout the world have dramatically influenced the processes for research collaboration and international transfer of new technologies. While there is no conclusive evidence whether stronger IPRs enhance or impede the availability and diffusion of new technology to developing countries, it is important that research institutes carefully consider their IP management strategies and “freedom to operate” prior to embarking on new R&D projects. Given the general situation of “weak” protection of biotechnology inventions in most developing countries, and the fact that patents for key enabling biotechnologies are primarily in force in highly advanced countries (e.g., USA, Canada, Japan, EU countries), problems of intellectual property infringement (of inventions protected in industrialized, but not developing countries) may not be too serious. This could of course change in the future.

Environmental and biosafety regulatory issues

Although there has not been one documented case, so far, of any environmental or human health damage caused by GMOs, there are some aspects of the risk profile that are not known, simply because the accumulated knowledge derived from the commercial-scale release of GMOs is still limited. This lack of familiarity has resulted, in a large number of countries, in stringent biosafety regulations and sluggish decision-making, thus adopting a precautionary approach to the diffusion of GMOs. It is important to point out that research can enhance familiarity with biotechnologies and contribute to informed biosafety decision making through risk assessment studies.

Consumer acceptability

Consumers in Europe, to a lesser degree the United States and some countries in Asia, have not been supportive of current biotechnology products. There is an increasing body of literature documenting this phenomenon; however, the important factor is that consumer groups in Europe and Japan have been very vocal about their opposition to biotechnology and have managed to exercise political pressure on governments to stop the development of biotechnology products. According to Paarlberg (2001), the consequence of this political pressure is that developing countries may have an even smaller probability of accessing biotechnologies suited to answer their problems. This is because developing countries are afraid that Europe and Japan will shun imports from

² Estimates of the distribution of rents from the United States of Bt cotton from Falck-Zepeda *et al* (2001, 2000a, 2000b) indicate that the innovators’ ability to capture all rents, as predicted by some economists, is limited. Other studies seem to support this conclusion.

countries using biotechnologies. Furthermore, Paarlberg argues that increased European Union regulations on labeling and identity preservation will further discourage the creation and diffusion of genetically modified crops in poor countries.

Dependence and un-sustainability of their biotechnology programs

Governments need policies and incentive mechanisms to encourage private-sector investment and participation in agricultural biotechnology. Public-and private-sector research should be consciously complementary and not competitive. The policy framework should not only promote the safe use of biotechnology but also ensure that policies are not a deterrent to investment by the private sector and to collaboration with global science. Each of these actions would help countries to move away from dependence on donor or external funding, and thus make their research more sustainable. This problem is not exclusive to biotechnology (Spielman and von Grebmer, 2004), yet the initial costs of developing these technologies may foster this type of problem

2.2 Evolving biotechnology capacity in developing countries

Recent reviews of agricultural biotechnology research capacity in different geographic regions show a mixed picture, very much reflecting the overall state of agricultural R&D investments. Reviews on Asia (ADB, 2001) and Latin America (Trigo et al., 2002) confirm a steady development of agricultural biotechnology R&D particularly in relatively large developing countries with well established infrastructure for research: Argentina, Brazil, Mexico and Chile in Latin America; and, China, India, Indonesia, Malaysia, The Philippines and Thailand in Asia. In these countries, human and financial resources allocated to biotechnology R&D are relatively high, experience with GMO testing and commercialization is growing, and government support programs and policies actively encourage R&D. It is no surprise that research institutes in the countries mentioned above are also actively involved in bilateral and international collaborative research programs in agricultural biotechnology.

The situation in sub-Sahara Africa stands in sharp contrast with that found in Asia and Latin America. Surveys by ISNAR and IITA (1999) and Alhassan (2003) indicate that although biotechnology applications are increasingly incorporated in agricultural research programs, they primarily involve applications of cell biology (micropropagation) and disease diagnostics, while more advanced applications are found only in a handful of institutes, most notably in South Africa. Furthermore, research efforts are scattered over a wide range of products and institutes without critical mass, and most often heavily dependent on donor funding. Advancements in agricultural biotechnology are severely constrained by a lack of funds, skilled human resources, and equipment. Government priorities and policies to support agricultural research in general, and agricultural biotechnology in particular, are lacking or not being implemented.

3. MEASURING RESEARCH CAPACITY

Given the situation above, several questions come to mind when considering capacity development among public institutions. These include: What are the specific investments in human and financial resources that developing countries have made? What

expectations and priority setting guided these investments? And, what outputs are derived from such investments?

Before looking at outputs however, it is first important to understand the investments made in research capacity and infrastructure. To accomplish this, a study was initiated for developing countries that included a series of indicators (Falconi, 1999). To achieve consistency between countries, the survey instruments used in our six partner country case studies were designed to include a common typology of research institutes and core variable definitions. The research institutes included in this study were:

- Private commercial firms (input companies, farm sector and food processing companies)
- Private non-commercial organizations (foundations and non-governmental organizations)
- Public sector (national institutes for agricultural research and universities)

Presently, there are few outputs commercialized by the public sector from investments in plant biotechnology at this point, except for China (see, Atanasov *et al*, 2004). However, this may change for some countries included in the survey, especially if the cost of plant biotechnology research decreases over time, and public sector research systems in developing countries gain the skills and infrastructure necessary to produce appropriate biotechnology outputs, as well as develop dissemination channels for their products.

In these studies, research staff includes individuals who hold a research position with at least a BS degree or its equivalent. Research staff included personnel in Management positions, such as directors and heads of research programs. Personnel data reported in the survey in both head count and full-time equivalent (FTE) researcher year terms and adjustments were to account for part-time commitments. Research expenditures include personnel, operational and capital expenses. Research expenditures have been deflated to account for inflation. Real expenditures have been converted to an internationally comparable standard by adjusting for differences in Purchasing Power Parity (PPP) Index with base year of 1985 (Heston and Summers, 1991). The expenditures adjusted to PPP dollars will be used to make inter-country comparisons of expenditure levels.

3.1 Research & Development investments in agricultural biotechnology in selected countries

During the period of analysis, total expenditures in agricultural plant biotechnology research measured in real 1985 US\$ Purchasing Power Parity (1985 US\$ PPP) totaled 508 million dollars (see Table 1). Investments in plant biotechnology research increased in China, Indonesia and Mexico (see Figure 1)³. Expenditures for Kenya, Zimbabwe and Colombia remained relatively static during the period of analysis. It is important to reiterate that investments in Kenya and Zimbabwe fluctuated significantly over the period of the survey as a result of donor funding during the period.

³ Please note, all figures at end of text.

Table 1. Total expenditures for plant biotechnology research in selected countries

Country	Years	# Of Institutes Surveyed	Total expenditures for survey period (Million 1985 US\$ PPP)
China	1986-1999	22	158
Colombia	1985-1997	10	15
Indonesia	1989-1997	8	116
Kenya	1989-1996	6	11
Mexico	1985-1997	14	193
Zimbabwe	1998-1998	6	15
Total			508

Source: ISNAR's Agricultural Biotechnology Indicator Studies

The survey data pertaining to the structure, organization, human resources, expenditures, and financing of biotechnology research are analyzed below. The evolution of the agricultural biotechnology research in the six selected countries is analyzed in relation to structure and organization, human resources, expenditures and sources of financing.

Structure, organization and sources of funding

Table 2 presents the average percentage distribution by public and private research institutions. Public-sector organizations primarily implement agricultural plant biotechnology research in the six countries included in the survey. Although the participation of the private sector had a low during the period of the survey, this sector had higher annual growth than did the public universities (except in Indonesia). Moreover, universities showed higher fluctuations and/or declines in research investments in these countries. This can probably be explained by the cyclical nature of donor funding and economic recession. For example, the departments of biochemistry and crops sciences of the University of Nairobi and the University of Zimbabwe received a substantial lump-sum donation in early 1990s that distorted their research expenditure figures during the period of analysis.

Table 2. Percentage Composition by Type of Institution and Country

	China		Colombia		Mexico		Kenya		Indonesia		Zimbabwe	
Type of Institution	1985	1999	1985	1997	1985	1997	1989	1996	1989	1997	1989	1998
Public – Research Institute	89	72	0	34	50	60	47	72	66	85	1	81
Public – University	11	28	41	27	50	28	49	24	14	11	98	3
Private Non-Commercial	0	0	0	14	0	4	4	4	0	1	0	16
Private - Commercial	0	0	59	24	0	8	0	0	20	3	0	0
Total	100	100	100	100	100	100	100	100	100	100	100	100

Source: ISNAR's Agricultural Biotechnology Indicator Studies

In the case of Mexico, government funds many universities, so the 1995 recession could be a factor affecting public universities' decrease in allocation of research investments from 1985 to 1997. These results are in contrast with results from other research efforts elsewhere. Byerlee and Fischer (2000) indicate that the majority of investments (and most of research effort) are conducted by the private sector internationally. However, their results are directly influenced by the amount of research done by multinational corporations, particularly in developed countries. Public funding of biotechnology activities is also shown in Figure 2. Colombia is an interesting case where coffee producer levies were used to finance research in coffee biotechnology in the mid-1980s. Coffee levies represented up to 59% of plant biotechnology investments in Colombia during the mid-1980s.

Public research institutes showed not only the highest share of financial resources but also the highest annual growth rate (Kenya 9%, Indonesia 30%, and Zimbabwe 70%). Furthermore, high annual growth rates were accompanied by a concentration of financial resources on few public research institutes. KARI in Kenya accounted for 70% of total expenditures in 1996, BRI in Zimbabwe 80% in 1998, RIFC, RDCB and IUC in Indonesia 70% in 1997, and CINVESTAV-I, CICY and IBT-UNAM 55% in 1997. The composition of Colombia's biotechnology research has changed in 1997 where more public institutes and universities, and private non-commercial institutions have increased investments in agricultural plant biotechnology research. On the other hand resources in China are concentrated around the research institutes, although funding at the university level has increased significantly.

Figure 3 presents sources of funding for agricultural biotechnology research activities in the six countries. The donor share in total expenditures has been considerable at Kenya and Zimbabwe. Donor contributions there represent an average 58% in Kenya and 50% in Zimbabwe of total expenditures on agricultural biotechnology. Public research institutes in these two countries were mainly funded by donor contributions, which were concentrated to the main research institutions. KARI in Kenya accounted for almost 85% of total donor support in 1996 and BRI in Zimbabwe almost 90% in 1998. Nonetheless, donor contributions to the development of agricultural biotechnology research programs will probably change significantly depending on pledges of support by foreign governments and multilateral development agencies but also on the socio-political climate in the country. It is important to point out that the viability or maintenance of these levels of funding will be compromised in the medium term if there is no effort to get some funding from local sources. Otherwise, the efforts made for the development of agricultural biotechnology could be endangered in both countries. Biotechnology activities done by private non-commercial organizations are funded by taxes on their commercialized commodities and sales of products.

Table 3. Indicators of plant biotechnology capacity, selected countries, 1989-1996

Indicator\Country¹	Kenya	Zimbabwe	China	Mexico	Indonesia	Colombia
Total plant biotechnology expenditures (Million 1985 US\$ PPP) ¹	11	10	95	133	98	10
Agricultural biotechnology research intensity ratio (%)	0.025	0.076	0.003	0.046	0.014	0.008
Average expenditures per plant biotech researcher (Thousands 1985 US\$ PPP)	42.37	60.34	31.52	117.21	56.88	23.65
Average number of plant biotechnology researchers (Ph.D. M. Sc. And B.S.)	35	28	375	149	202	56
Average number of plant biotechnology researchers with Ph.D.	20	10	52	67	68	9

Source: ISNAR's Agricultural Biotechnology Indicator Studies

In China, Mexico and Indonesia the government share in total expenditures has been considerable for public research institutes and the biotechnology programs at the universities. Government contribution represents about 88% in China, 61% in Mexico and 83% in Indonesia of total expenditures on agricultural biotechnology. Donors share, not as significant as in Kenya, accounted for almost 10% in China, 16% of Colombia, 32% in Mexico and almost 7% in Indonesia. It is interesting to note that some public research institutes and universities are funding their biotechnology research activities from non-traditional sources of funding, such as sales of products and services and contractual arrangements. Although these sources of funding are still minimal, they have increased during the period of analysis. As expected, contracts largely fund biotechnology activities carried out by private non-commercial organizations, while some if their products finance private commercial organizations.

The limited funding (or non-existent in the case of Kenya and Zimbabwe) from non-traditional sources (contracts, sales of services and products) of the public research institutes and universities indicates a limited relation between those public entities and the private sector. Donors' contributions are important sources of funding in Kenya, Mexico and Zimbabwe. A closer look at how donor funds are distributed reveals that most donor contributions were oriented to infrastructure, consultants, and operations. In the period of analysis, these categories accounted for almost 95% of donor funds. It is interesting to note that the share of donor contributions going to operations and consultants decreased during the period, while infrastructure increased. Sharp increases in the number of researchers and the need to modernize laboratories may explain this fact. On the other hand, it is surprising that donors' share of training is almost nil in Kenya and Mexico. However, in Zimbabwe donor's share to training was almost 20% indicating an interest of building human capacity in biotechnology.

Human resources

Figure 3 presents information on agricultural biotechnology researchers with a Ph. D. degree. In Kenya and Indonesia, the number of researchers more than doubled. In China, Mexico and Zimbabwe researcher numbers quadrupled. In Colombia, the total number of research professionals increased more than 10-fold, but most of the increase in research personnel occurs at the M.Sc. and B.S. level. This may be explained by the emphasis on ornamental and floriculture efforts directed particularly to tissue culture. The number of Ph.D. holders increased significantly in all countries. For example, in Kenya, Indonesia and Zimbabwe the number of Ph.D. holders at least doubled, whereas in Mexico and Colombia the number of Ph.D. increased ten fold. China is a very interesting case where the number of Ph.D. holders increased dramatically from 5 in 1986 to 203 in 1999. These groups of professionals form the basis for future agricultural biotechnology.

Although the number of scientists working in biotechnology has increased, they are, nonetheless, concentrated in a few public research organizations. Around 45% of the researchers are located in KARI (Kenya), 60% in only four research Mexican organizations: CINVESTAV-I, CICY, IBT-UNAM, and the National Research Institute on Forestry, Plants and Livestock (INIFAP), 60% in only three Indonesian research organizations: RIFCB, RDCB and IUC, and 70% in only three Zimbabwean research organizations: DRSS, BRI and UZ. China is a counterexample where scientists are distributed among a large number of institutes and universities. However, this may be a consequence of the sheer size of the Chinese agricultural research system.

Investment expenditures

Because the rate of growth of the number of researchers is higher than the rate of growth of expenditures, this has led to significant declines in expenditures per researcher. The only exceptions are China with a relatively constant level of real expenditures and Indonesia where there was a small increase level of expenditure per researcher. This trend could change depending on the behavior of multilateral and bilateral investment institutions and the general state of the countries economies. It is worthy to highlight that expenditures per researcher in Mexico and Indonesia were relatively higher than those of the smaller countries in the sample (Colombia, Kenya and Zimbabwe). These figures imply that Mexican and Indonesian researchers have more resources and higher probabilities to generate biotechnology research outputs and may be an additional signal from their respective governments about their commitment to biotechnologies in general.

One of the most widely used measures of measuring national commitment to a research agenda is the research intensity ratio. The agricultural biotechnology research intensity ratio is measured by dividing investments in agricultural biotechnology research relative to Agricultural Gross Domestic Product (AG GDP). As can be seen in Figure 4, even though the agricultural research intensity ratio has grown annually, the percentage of agricultural biotechnology research expenditure in relation to Agricultural GDP is quite minimal, on average 0.002% in China, 0.007% in Colombia, 0.09% in Zimbabwe, 0.04% in Mexico, 0.025% in Kenya and 0.014% in Indonesia. During the same period the percentage of agricultural biotechnology research expenditures to total agricultural research expenditures was in average 0.55% for China, 1.2% for Colombia, 1.5% for

Kenya, 6.4% for Mexico, 6.8% for Indonesia and 4.1% for Zimbabwe. On average, Indonesia and Mexico invested more than the small countries in the sample.

There is no set rule for how much of the agricultural research budget should be allocated to biotechnology. The World Bank (1981) and SPAAR (1996) have suggested a 2% of agricultural GDP as a target for finance of agricultural research by developing countries. However, there are no guidelines for components within agricultural research. But for comparison, the Consultative Group for International Agricultural Research (CGIAR) spends about 8% of its budget to biotechnology research in 1997, and the United States allocated 13% of its agricultural research expenditures to biotechnology in 1992 (Fuglie et al., 1996 and Caswell et al., 1994). In addition, the amount of investments in agricultural biotechnology may be related to the relative strength of the agricultural research system in general.

Byerlee and Fischer (2001) in a rough classification of National Agricultural Research Systems (NARS) based on the plant breeding and molecular biology capacity, indicate that “stronger” NARS may invest more in agricultural biotechnology than “weaker” systems. The authors estimate that the stronger NARS (Brazil, China, Mexico, India, and South Africa) indeed invest 5-10% of their budgets in agricultural biotechnology applications. Huang, Rozelle, Pray and Wang (2001) highlight the situation in China. According to these authors in 1999 the Chinese government has invested around 9% of their agricultural research budget in biotechnology. Furthermore, they estimate that these investments represent around half of the developing world investments in agricultural biotechnology.

3.2 Research capacity and results

One measure of institutional capacity for biotechnology research can be examined by documenting their research outputs, such as the successful development of GM crop innovations. In this regard, a meeting was organized to review such progress, selecting 16 countries that reflect investment timeframes of over 10 years. One of the initial findings of this meeting and study, referred to as *Next Harvest*, was that while intellectual property issues have thus far proven manageable for most countries, high regulatory costs found to ensure safety, increased public concerns, and lack of knowledge regarding the potential benefits and risks of biotechnology confine research products to the laboratory. This is seen when the number of research events in confined testing is compared with further requirements needed for advancement.

For these countries, (China, India, Indonesia, Malaysia, Pakistan, Thailand, The Philippines, Argentina, Brazil, Costa Rica, Bulgaria, Egypt, Kenya, Nigeria, South Africa, and Zimbabwe⁴), significant investment has been made in biotechnology and regulation. Successful events, that are stable and transmit expression over generations, were clearly demonstrated from 76 public institutions. In this regard, 46 crops have been transformed, for a wide array of locally important traits. This is almost twice the number

⁴ These countries are a subset of those from which FAO has collected biotechnology and regulatory information (FAO-Biodec). For each country, in depth analysis and strategic reviews are occurring.

of crops transformed at CGIAR centers. In addition, germplasm being used and transformed is often local public lines, or other local breeding material, which increases the importance of such work (Atanassov *et al*, 2004).

Success of this national capacity can also be seen from the range of traits undertaken for transformation. From the *Next Harvest* data, the most important traits include: insect resistance, virus resistance, herbicide tolerance, a combination of agronomic properties and product quality traits, and, fungal and bacterial resistance. The actual genetic material incorporated also indicates wide access to and use of proprietary material, demonstrating research collaboration and capacity to insert and express the array of genes employed.

However, final assessment of this work, and the opportunity to move towards outcomes, will be through products available to smallholder or local farming communities. This will of course be contingent on demonstration of safety, and appropriate mechanisms for the distribution of these new materials.

5. CAPACITY BUILDING FOR BIOTECHNOLOGY: CONCLUSIONS AND IMPLICATIONS

Among the six developing countries studied for research capacity and investments, each received government support for the establishment of biotechnology research centers, the creation of post-graduate training and research, and the formulation of regulatory frameworks (for biosafety and intellectual property rights). These efforts provide a good foundation for further development of biotechnology. However, a comprehensive strategy is lacking for biotechnology capacity development and expectations for this capacity as part of the larger agricultural knowledge system. With this in mind, the following findings and implications are presented.

1. *Successful implementation demonstrated.* Important progress has been achieved from the resources (human and financial) that have been available during the period studied. This includes progress in biotechnology research, and for biosafety and regulatory frameworks development. Existing capacity, while limited, has nonetheless completed important tasks. With increased management and better, more cohesive strategies, one would anticipate accelerated progress. This may mean that more funding is needed per researcher before building new capacity, especially if funding is not available to sustain additional infrastructure and personnel.

2. *Building a strong public sector.* While capacity is evident, developing further management and analytical capacity is needed for public institutions that set agendas and priorities for biotechnology. These are particularly needed to ensure existing capacity serves rural community needs. Existing personnel will require further support as they are called to contribute to public awareness, and spearhead collaboration with the private sector on product development and diffusion.

In addition to research capacity, the public sector or government is also responsible for regulatory decision making for biosafety. In fact, many research scientists go on to

become regulatory officials, or part of the regulatory process, or serve on institutional biosafety committees. While much has been achieved in building regulatory capacity, further work is needed not only within the system, but to effectively deal with external pressures to the regulatory system from external factors, such as trade and markets (Cohen and Paarlberg, 2004). This additional capacity will strengthen the probability that efficient, timely and safe regulatory decisions can be made.

3. *Private sector relations.* In the countries reviewed, the creation of biosafety committees and the revision of property rights legislation should favor private sector participation in agricultural biotechnology research. The situation in China is different as the agricultural institutions in the public sector have promoted biotechnology innovation but commercialization has been hampered by conflicts with institutions in the public sector dealing with trade with regard to their intended objectives. There have been some initial public-private partnerships currently being implemented in China. This is generally not the case in other developing countries. Participation by the private sector in the biotechnology innovation process remains limited (Spielman and Von Grebmer, 2004). This is the case among all six countries during the period of the survey and for those surveyed as part of the *Next Harvest* study.

4. *Importance of priorities and research agendas.* Human capacity and impact from research will benefit from a strategy to foster biotechnology, including priority setting and research agendas. Governments need to make strategic decisions at the national level with a clear understanding of the costs, benefits and risks of biotechnology and its potential to help meet national goals. Policy makers need tools for planning and priority setting to help make informed trade-offs among commodities and research problems. There is also a need for more national and institutional commitment to fund (or raise sustainable funding for) agricultural biotechnology research and development. Strategic planning for future capacity building should be part of this process.

These planning decisions are crucial to investments in biotechnology. As discussed in this paper, there is no set rule that cuts across all countries and regions with regard to an appropriate level of funding and capacity for biotechnology. Each country determines its own level of investments, fitting its needs and capabilities. This should be part of a process that evaluates biotechnology research in the context of country priorities and needs, and also looks at alternative solutions.

A decision to provide support requires each country to identify funding sources and evaluate their stability. As demonstrated above, most countries endured significant investment fluctuations and dependence on donors. If biotechnology is a desired innovation, then countries need to consider increasing domestic funding for high priority activities. For poorer countries, this may imply tight coordination between the public sector, donors, international research centers and the private sector. This coordination of roles does not have to be a formal process, but rather a response to an increasingly vibrant private sector in the country or region.

5. Time for evaluation and review. This report described GM crop outputs obtained from public research. While good progress can be seen from this work, it is time for more formal evaluations of capacity and investments. This is especially true as many of these programs have been running for over 10 years.

Biotechnology is a rapidly growing and changing endeavor, and capacity and investments must adjust accordingly. Also, international funding and research organizations have changes in their missions, programs and projects. The capability to analyze and adjust capacity for biotechnology research is essential to keep pace with current scientific advances and new research priorities (Frederick and Virgin, 1996). From this starting point, evaluation criteria were established for building biosafety capacity (Virgin and Frederick, 1966). Such methodologies can be considered for biotechnology research.

In addition, broader evaluations have been done for research and development originations globally. Lessons from this process, e.g. evaluating capacity development, are also crucial. This would require fine-tuning a well-established process for agricultural research to include or specifically tackle biotechnology. The goal here is that such evaluations contribute towards current capacity development planning, and to the organization's performance (Horton et al., 2003).

In conclusion, findings from our surveys show that most research institutions are in the initial stage of developing biotechnology research capacity. Although expenditures on agricultural biotechnology annual research investments grew at a small rate, the number of researchers increased at a higher pace. In addition, the proportion of biotechnology expenditures to total agricultural research expenditures was small, with the public sector accounting for most.

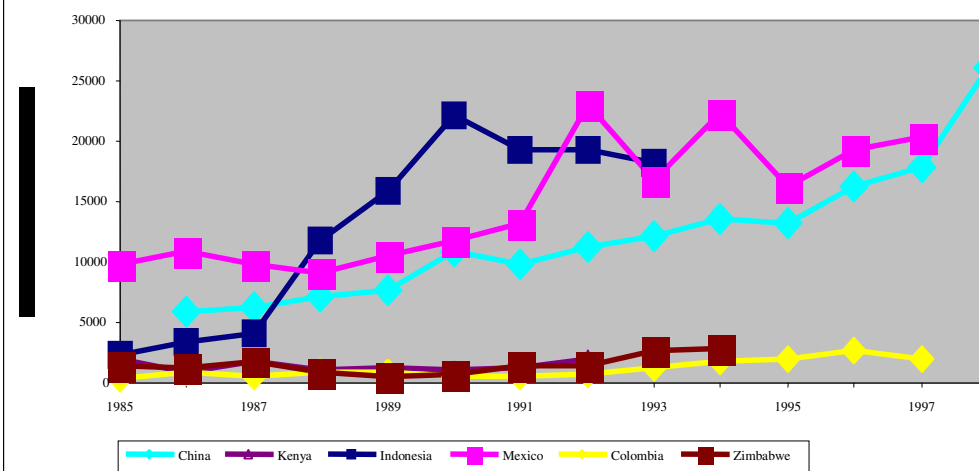
As we would imagine, the scientific discovery process is maximized when human and financial resources are available to researchers over a longer period of time and at a relatively secure level. Unfortunately, this is not the case in many countries of the developing world. This same stability is needed for agricultural research in general, and with the increasing capacity needed for biotechnology, future integration of planning, and institutional capacity will be essential. Finally, finance and capacity may be best provided in ways to address specific constraints, no matter the technologies chosen, as this could be more responsive to stakeholders, and easier to justify.

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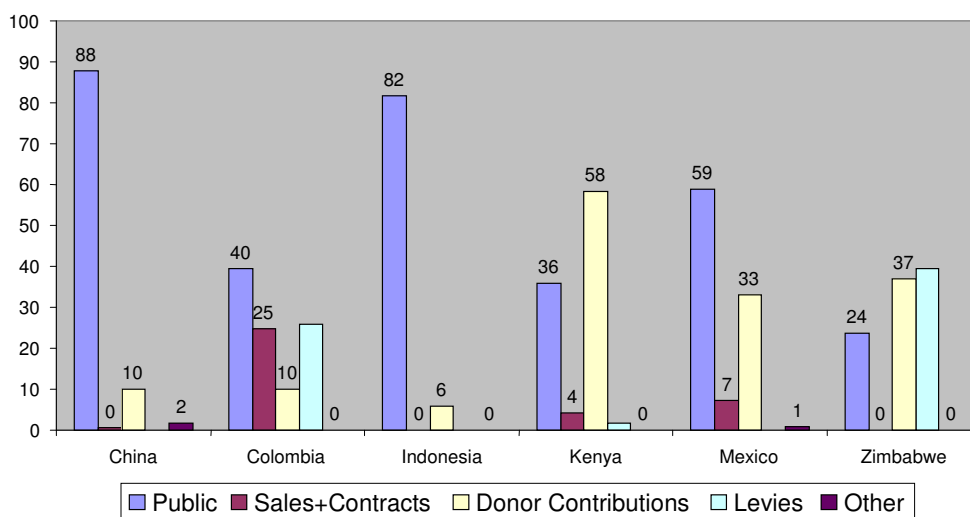
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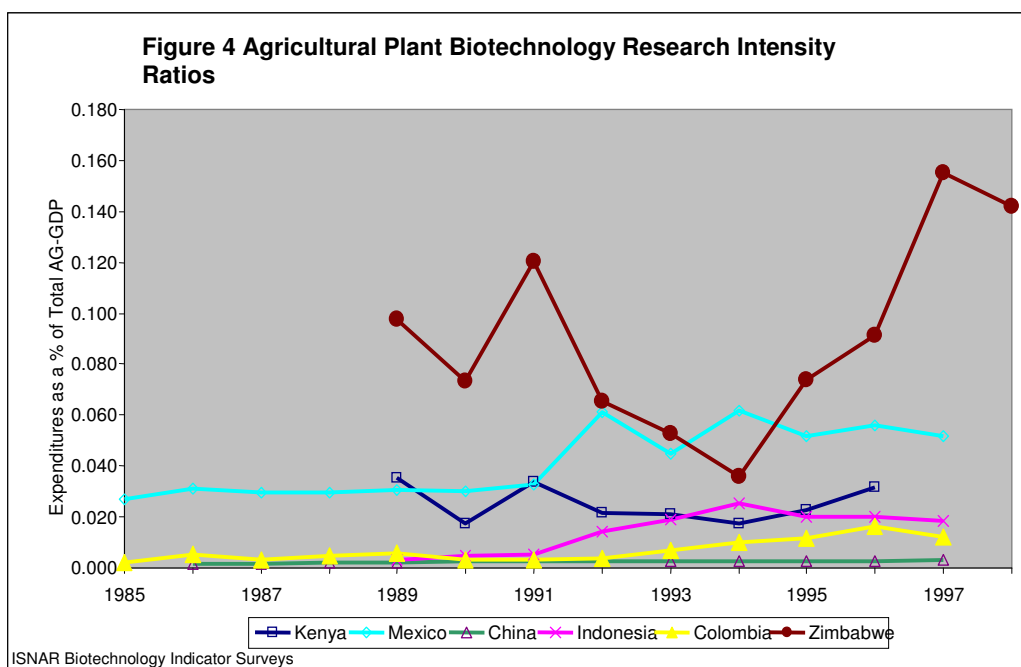
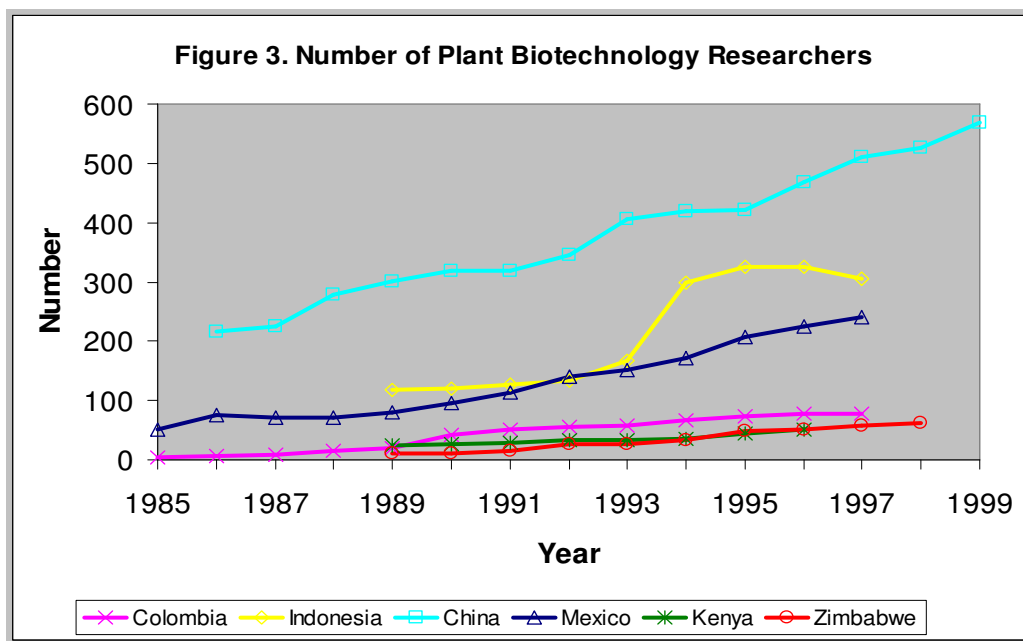
Figure 1. Total Expenditures Plant Biotech Research



ISNAR Biotechnology Indicator Surveys

Figure 2. Plant Biotechnology Source of Funding (1989-1996)





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