The Role of Biotechnology for Global Food Security
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Paper submitted for the special issue of Agrarwirtschaft

Abstract
Biotechnology per se is not a panacea for the world’s problems of hunger and poverty. However, genetic engineering in particular offers outstanding potentials to increase the efficiency of crop improvement. Thus, biotechnology could enhance global food production and availability in a sustainable way. Two case studies from Kenya and Mexico also demonstrate that transgenic crops are very appropriate for agricultural producers and consumers in developing countries. As the entire technology can be packaged into the seed, it can easily be integrated into traditional smallholder farming systems. Except for a few innovative transfer projects, though, the application of biotechnology until now remains concentrated in the industrialized world. Combined with insufficient own scientific and regulatory capacities, the increasing privatization of international agricultural research and the strengthening of intellectual property rights complicate the access of developing countries to biotechnology. Profound institutional adjustments are essential to ensure that biotechnology does not bypass the poor.

Keywords: biotechnology; food security; agriculture; developing countries; economic impact; technology policy; technology transfer; intellectual property rights

1 Introduction
During the last decades, the number of hungry people at the global level declined both in relative and absolute terms. In part, this was made possible through remarkable technological progress in agriculture, involving the introduction of new high-yielding varieties of major food grains, combined with a more intense use of complementary inputs, such as agrochemicals and irrigation, as well as improved farm management practices. Known as the green revolution, these technological advancements doubled the grain yields in large parts of Asia and Latin America, entailing improved food availability for poor consumers at affordable prices.

However, this success story cannot hide the fact that hunger and poverty remain pervasive in the early twenty-first century. Today, around 800 million people still suffer from chronic food insecurity, most of them living in developing countries (FAO, 1999). It is estimated that population and income growth will lead to a further doubling of food demand over the next generation (MCCALLA, 1999, p. 99). At the same time, the natural resources available for agricultural production, particularly land and water, are becoming ever more scarce. Hence, increases in food production will essentially have to come from gains in the resource productivity. Yet growth in farmers’ crop yields has been slowing down since the 1980s, and in some regions of the world, grain yields have even tended to level off (PINSSTRUP-ANDERSEN et al., 1999, p. 14). Evidently, the current state of agricultural technology will not suffice to meet the production challenges ahead. Innovative technologies have to be exploited in order to enable sufficient food availability in the future.

In this context biotechnology offers promising potentials. New tools of molecular genetics and genetic engineering in particular help to increase the efficiency of crop improvement programs. Thus, biotechnology could boost global crop output in the future while promoting environmentally friendly agricultural production patterns (e.g., SEERAGELDIN, 1999; KENDALL et al., 1997). The adoption of genetically modified crops in agricultural practice followed an exponential profile during the last few years. In 1996, 2.8 million hectares were grown worldwide with transgenic crops; by 1999 this area had already multiplied to 39.9 million hectares (cf. JAMES, 1999). Most of the recombinant technologies developed up till now
involve soybeans, maize and cotton, which have been endowed with herbicide tolerance or insect resistance. But many other biotechnology products are already in the research pipeline.

Apart from its importance to sustain the global equilibrium between food supply and demand, biotechnology could also contribute to enhanced food security through generating additional purchasing power. Agriculture is still a major source of income and employment in many developing countries, so a gain in sectoral profits through appropriate farm technologies also induces positive growth effects for the overall economy. Crop biotechnology is especially appealing because it is considered to be scale-neutral. Hence, large and small farms could benefit alike. Biotechnology applications, however, thus far remain concentrated in the industrialized world, notably in North America (see Figure 1). The private sector usually decides the direction of related research and development (R&D). By nature, private research efforts focus on areas with large market potentials. So there is the risk that biotechnology will bypass the poor, unless the specific needs of marginalized groups are addressed through public action. The private sector R&D dominance is also one reason why critics consider modern biotechnology to be inappropriate for the developing world (e.g., ALTERI and ROSSET, 1999, p. 156).

2 Biotechnology Potentials and Risks

Biotechnology is broadly defined as “any technique that uses living organisms or substances from those organisms to make or modify a product, improve plants or animals, or develop microorganisms for specific uses” (PERSLEY, 2000, p. 5). Here, however, we focus on the use of genetic engineering in crop improvement. This is a rather narrow view because many other biotechnology tools, such as tissue culture and molecular markers, are very promising, too.

But genetic engineering is the most controversial among the biotechnology tools, and covering the whole range of techniques in greater detail would break the scope of this paper.

2.1 Potentials of Biotechnology in Crop Improvement

Biotechnology should not be understood as a substitute for traditional tools of crop improvement. But integrating recombinant techniques into conventional breeding programs could substantially enhance the efficiency of agricultural R&D. On the one hand, breeding could be accelerated due to the more targeted transfer of desired genes into the crop. On the other hand, biotechnology could bring forth new crop traits that are not amenable to the conventional approach. Whereas traditional crossbreeding is confined to the exchange of genetic material within a certain crop species, recombinant techniques enable the transfer of valuable genes across species and even across kingdoms. A case in point is Bt maize, where a gene of the soil bacterium Bacillus thuringiensis (Bt) has been incorporated into the plant genome to confer resistance to particular insects. The major transgenic breeding objectives are described in the following.

Agronomic traits. The category of agronomic traits embraces all genetic modifications of plants that help to stabilize or increase the yields in farmers’ fields. Since the immediate benefits of such traits accrue at the level of agricultural production, they are often referred to as ‘input traits’. Prominent input traits are mechanisms of pest and disease resistance, which are often encoded by only a single gene (monogenic traits). Different transgenic pest and disease resistances have already been commercialized. In assessing the potential value of such traits it has to be considered that global crop losses induced by biotic stress factors reach a level of 25-30% (OEKRE et al., 1994). Biotechnology could substantially reduce these losses without the need for increased pesticide applications. Other desirable agronomic crop traits include enhanced genetic yield potentials and tolerance mechanisms to abiotic stresses, such as drought, coldness and nutrient deficiencies in soils. Since these latter traits are usually determined by multiple genes (polygenic traits), the research is often more complicated. Recent advances in molecular mapping and functional genomics, however, demonstrate that related biotechnology products are also quite realistic in the near to medium-term future (e.g., ABELSON and HINES, 1999). Thus, improved crop varieties could also be tailored to marginal agroecological regions, which have been largely neglected by the green revolution.

Quality traits. In contrast to the agronomic traits, which help increase the quantity of agricultural production, quality traits are related to the appearance or the chemical composition of the crop product. Hence, they are often referred to as ‘output traits’. Quality traits can include enhanced densities of macro- and micronutrients essential for healthy human diets. If such traits are incorporated into staple food crops they could be beneficial.
especially for poor population segments that often lack purchasing power to buy sufficient amounts of higher-value and more nutritious foods. Researchers, for instance, managed to develop transgenic rice varieties with significantly enhanced vitamin A contents, now being used in rice breeding programs (Potrykus et al., 1999). It is estimated that worldwide more than 400 million people suffer from vitamin A deficiency which often leads to irreversible blindness and other deleterious health problems. Promising advances in biotechnological research to improve the micronutrient density in plants have also been reported for a number of other important vitamins and minerals. Although somewhat less related to food security, biotechnology also permits to modify plants in a way that they produce significant amounts of special chemicals, such as vaccines, other pharmaceuticals or biodegradable plastics.

2.2 Risks of Biotechnology

Besides the great potentials of biotechnology for increased food production and agricultural productivity, the risks must not be neglected. Often fears have been articulated that new risk dimensions for the environment and for human health could occur due to the direct manipulation in the genetic makeup of organisms. As human knowledge is limited, the existence of unknown risks cannot be ruled out with absolute certainty, neither for transgenic crops nor for any other technology. According to current scientific knowledge, though, there are no indications that genetically modified crops are per se more dangerous than traditionally-bred varieties (cf. Cook, 2000, p. 123). This does not mean that there are no risks at all. However, the predictable risks are not related to the biotechnological process but to the end-product to be released. Thus, risk assessment studies have to be carried out on a case-by-case basis for each individual technology product.

Environmental risks that need to be considered include the possible loss of biodiversity, detrimental effects on natural food chains and the emergence of more aggressive pathogen populations. Health risks include the possible occurrence of undesirable toxic byproducts in the crop, the transmission of antibiotic resistances (used as marker genes) to microorganisms of human digestion and unknown allergic reactions by food consumers. Generally, the individual risk aspects apply to developed and developing countries alike. Yet it is important to note that the likelihood of transgenes escaping into the wild through cross-pollination is higher in the developing world. The major centers of agricultural biodiversity are found in the tropics and subtropics (cf. Virchow, 1999, p. 12f.), so that more wild relatives of domesticated species are growing in the vicinity of farmland. If the transgenes encode traits of substantial competitive advantage, there is the risk that some of the natural vegetation is suppressed.

A responsible management of biotechnology is a prerequisite for sustainable agricultural development, and it requires that effective regulations for biosafety and foodsafety are established wherever transgenic crops are to be developed and released. Responsible technology management, however, must not be confined to the risk side only. Risks should always be juxtaposed to the potential benefits, and certain residual risks appear tolerable if they are offset by much higher benefit prospects. On the benefit side, it must not be forgotten that biotechnology could also bring about substantial positive environmental effects, such as lower conventional pesticide applications or reduced agricultural area expansion into ecologically fragile environments.

Apart from the mentioned environmental and health risks of transgenic crops, there are also concerns which are rather socioeconomic. Biotechnological techniques, for instance, could alter international trade flows to the detriment of many developing countries: trade with agricultural raw products could be substituted, if tropical plants are adapted to the temperate zone or their products are produced in the lab, as is expected for vanilla and other valuable substances. Likewise, if biotechnology R&D would only benefit the rich while neglecting the needs of the poor, the innovation could engender an aggravation of existing income disparities. These kinds of risks should not be underrated, but it has to be clear that they are not inherent to biotechnology. Any far-reaching new technology can cause undesired equity effects under unfavorable economic and social framework conditions. Problems of poor people’s access to biotechnology are discussed more explicitly in later sections.

3 Potential Biotechnology Benefits in Developing Countries

The socioeconomic implications of genetically engineered crops in developing countries are the subject of heated debates among advocates and opponents of biotechnology. As only very few developing countries have some preliminary experience with transgenic products, concrete evidence is so far hardly existent. To improve the information base, several ex ante economic case studies have recently been carried out in different developing countries. Two of these studies – one dealing with virus-resistant sweetpotatoes in Kenya, and the other with virus-resistant potatoes in Mexico – shall briefly be presented here (for more details see QAIM, 2000). Both technologies build on transgenic tools. They are being developed within international collaborative research projects, involving both public and private sector organizations.

3.1 Biotechnology Projects

Farmers of vegetatively propagated root and tuber crops in developing countries suffer significant yield losses induced by viruses, and conventional resistance breeding has shown
only limited success. Recombinant techniques bring about new opportunities to develop high-yielding, virus-resistant varieties through the introgression of viral coat protein or replicase genes into the plant genome.

Transgenic sweetpotatoes in Kenya. A research project to advance non-conventional virus resistance in sweetpotato was launched in the early 1990s by the private US company Monsanto and the Kenya Agricultural Research Institute (KARI). The project’s initial phase was co-sponsored by the United States Agency for International Development (USAID). In cooperation with KARI scientists, basic research components of the project – such as the development of suitable biotransformation and plant regeneration protocols – have been carried out in Monsanto’s USA laboratories. The transfer of the recombinant sweetpotato technology from USA to Kenya took place in 1999. A royalty-free licensing agreement between Monsanto and KARI has been signed, which allows KARI to use the technology and to share it with other African countries in the future. The next phase of the project is sponsored through the World Bank’s Agricultural Research Fund (ARF), and is institutionally supported by Monsanto, the International Service for the Acquisition of Agri-biotech Applications (ISAAA), and the International Potato Center (CIP). National biosafety guidelines are being established in Kenya, which are required to field-test the virus-resistant sweetpotatoes. If successful, the technology could officially be released in 2002. KARI will distribute the transgenic germplasm free of charge to the Kenyan farmers in the form of sweetpotato vines, a crop byproduct which is commonly used for plant propagation.

Transgenic potatoes in Mexico. Another collaborative project between Monsanto and the Center for Research and Advanced Studies (CINVESTAV) in Mexico was also launched in the early 1990s to make transgenic virus-resistant potatoes available to Mexican farmers. This project builds upon proven technology already commercialized by Monsanto in the USA. The technology transfer was brokered by ISAAA and is financially supported by the Rockefeller Foundation. CINVESTAV adapted the virus resistance technology to local requirements, and different transgenic potato varieties have been field-tested over the last few years. Pending the food safety approval, technology release is expected to occur as early as 2000. New potato varieties are usually introduced through the formal seed market in Mexico. The private potato seed producers will receive the transgenic germplasm from CINVESTAV without payment. Then they will multiply the technology and sell it to the farmers in the form of certified tuber seeds.

In both projects, Monsanto donated proprietary technologies and provided technological know-how without receiving a direct return. The company’s incentives, therefore, have to be assessed from a more strategic point of view. On the one hand, the public image of a multinational company becomes increasingly important, so that being part of philanthropic projects can be supportive for the long-term business success. On the other hand, the projects give Monsanto the opportunity to gain experience in hitherto unknown environments and to build up new institutional networks. The direct cooperation with local partners and the consolidation of national biotechnology regulatory mechanisms in Kenya and Mexico could well facilitate future commercial technology ventures.

3.2 Economic Technology Evaluation

The potential benefits of the described transgenic technologies in Kenya and Mexico have been quantified in a partial equilibrium framework using a closed-economy economic surplus model. The welfare effects for agricultural producers and consumers have been simulated over a 16-year period, starting from the time of expected technology release. As the technology outcome cannot easily be observed in the ex ante setting, the analysis builds on comprehensive discussions with researchers, supplemented by interview surveys of farmers and extension workers in the two study countries.

The innovations – i.e., virus-resistant sweetpotatoes in Kenya and virus-resistant potatoes in Mexico – are expected to bring about substantial yield gains through the reduction of presently occurring crop damages. Once acquired, the transgenic varieties can be reproduced by the farmers themselves, and an adjustment of the traditional cultivation practices is not required. Therefore, the risk for farmers associated with technology adoption is fairly low. The average annual gains in economic surplus resulting from the model computations are shown in Table 1.

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Both technologies will lead to sizeable welfare gains. Although the hecatareage cultivated with sweetpotato in Kenya is similar to the one cultivated with potato in Mexico, the projected overall economic gains are much higher in the case of virus-resistant potatoes. This is mainly attributable to two factors: first, the current virus-induced yield losses are more pronounced in Mexican potato production than in Kenyan sweetpotato production. Second, technology adoption rates are predicted to be higher in Mexico, because virus resistance is incorporated into a few well-established potato varieties with significant production shares. In Kenya, by contrast, farmers use a large number of local sweetpotato landraces because varietal preferences are very diverse. It will be more difficult, hence, to achieve the same technology penetration with only a limited number of transgenic varieties.

1 The closed-economy assumption is realistic in both cases because international trade in sweetpotato is almost nil, and also the traded amounts of potatoes in Mexico are negligible due to high import tariffs. These import tariffs will have to be gradually reduced under the North American Free Trade Agreement, but the implications for international potato trade flows are still unknown.
Table 1 also shows the distribution of technology benefits between agricultural producers and consumers. Farmers profit owing to the productivity growth in cultivating the respective crop; consumers profit through technology-caused food price decreases. While the welfare gains in Mexico are almost evenly distributed among producers and consumers, the benefit partitioning in Kenya is somewhat biased towards the farmers. This is so because sweetpotato is produced semi-subsistently, implying that producers retain part of the consumer surplus due to the utilization of the commodity in the farm household.

Often, new agricultural technology has been criticized to foster inequalities between small and large farms. In Kenya, the resource-poor, small-scale farmers are anticipated to become the main beneficiaries of new transgenic sweetpotato technology because they dominate the cultivation of the crop. Large commercial farms hardly grow any sweetpotato in Kenya.

However, the situation is different in Mexico, where potatoes are cultivated by both small and large farms. A further evaluation of technology distribution effects therefore appears instructive. In general, transgenic technology is considered to be scale-neutral because it is incorporated into the seed—a traditional, divisible and reproducible farm input. In fact, the productivity-increasing potentials of virus-resistant potatoes in Mexico are even higher for the smallholders, because they currently suffer the higher yield losses caused by viruses. But apart from the general suitability of a new technology, institutional aspects in technology diffusion play an important role for the actual outcome. It has already been mentioned that it is planned to disseminate the transgenic potatoes via the formal markets for certified tuber seeds. On account of resource restrictions small-scale potato producers rarely purchase certified seeds. Nonetheless, after a certain time lag the smallholders will get access to transgenic potatoes through an informal exchange of tubers between farmers. This mechanism will work at least for varieties which are used by both small and large farms. Yet, to some extent the small-scale farmers, particularly those located in more remote areas, use other potato varieties than the larger producers. Although the transgenic technology will be available for some of the varieties used by the smallholders, a bottleneck could occur in variety distribution. Taking this into account, Figure 2 shows the projected equity effects of transgenic potatoes among different farm sizes in Mexico.

In the present institutional situation, the benefit share attributable to the small potato farms would be lower than their initial production share, indicating a slight rise in income concentration. Such an undesired outcome could be prevented, however, through institutional adjustments. Alternative scenario calculations have been carried out assuming targeted policy support to improve the small farms’ technology access (e.g., a time-limited seed subsidy).

Figure 2 reveals that an appropriate technology dissemination mechanism could not only prevent widening disparities, but could even considerably improve income distribution in the Mexican potato sector. At the same time, the overall annual welfare gains would rise from 30.3 million US$ to 45.1 million US$.

The case studies from Kenya and Mexico emphasize the high benefit potentials of genetic engineering for poor agricultural producers and consumers in developing countries. Yet the Mexican case also shows that unfavorable framework conditions might hamper an equal benefit participation of certain disadvantaged population groups. From a development policy perspective it is important to identify possible institutional drawbacks through ex ante analyses and to abolish them by appropriate support. Especially ex ante analyses for crops of orthodox seed are needed because the conditions of R&D and technology diffusion may differ from those of vegetatively propagated root and tuber crops.

4 Access of Developing Countries to Biotechnology

Although the previous section clearly demonstrated the benefit prospects of modern biotechnology for developing countries, it must not be overlooked that the international evolution of the technology is predominantly driven by the industrialized countries. Technological advances in the favorable climates of the Northern Hemisphere are important to increase global agricultural production, thus lowering the world market prices of food. Yet, if biotechnology shall contribute to the achievement of local development objectives, it needs to be utilized, too, by the majority of small-scale farmers in low and middle-income countries.

A better access of developing countries to modern biotechnology is also necessary to avoid a widening technological gap between North and South. Since most developing countries so far lack the capacity to come up with their own biotechnology products, suitable technologies have to be imported from abroad. This section discusses the changing framework conditions of international agricultural research and the private and public sector roles in providing biotechnology to the poor.

4.1 Changing Framework Conditions of Agricultural R&D

With the advent of biotechnology, many of the framework conditions of international agricultural research are transforming with far-reaching ramifications for all players involved. The most important changes are the strengthening of IPRs and, associated with this, the growing importance of the private sector in plant improvement research. It is estimated that at the global level between 75 and 80% of all investments in agricultural biotechnology are made by private companies (QAIM and VIRCHOW, 1999, p. 37). Public universities are still vital for strategic biological research. But especially in the USA, the involved university
researchers often initiate new biotechnology startup firms on the basis of promising laboratory discoveries, so that related public research results become private property as well.

In parallel, the degree of concentration is increasing in the markets for biotechnology products. During the last four years, firm mergers, acquisitions and alliances worth over 25 billion US$ could be observed with immediate relevance to the agricultural sector. On the one hand, bigger companies buy up smaller ones, including innovative startup firms, that often lack financial resources and market experience to commercialize inventions on their own. On the other hand, horizontal integration between large multinational companies, such as the one between Hoechst and Rhône-Poulenc in 1999, and vertical integration between biotechnology firms and seed companies are also widespread. Some of the partly interlinked reasons for the observable industry consolidation are the following:

- It is reckoned that integrated life-science companies active in various sectors (e.g., agrochemicals, seeds and pharmaceuticals) allow the exploitation of synergy effects across branches in basic research.²
- Rising competition in the oligopolistic agricultural biotechnology industry requires that more and more basic and strategic research is carried out in-house. Basic research is associated with extended time lags between project start and final technology release. The R&D resources of one single company might be too limited to ensure a sufficiently high rate of innovation in the future.
- The development of biotechnology end-products requires access to intermediary technologies and tools that might, in many cases, already be patented by other companies. So firm integration can broaden the portfolio of accessible patents.
- For most of the crop biotechnologies, the high-yielding and adapted crop variety is the only vehicle of realizing the innovation at a large scale. Since crop protection companies are extending their biotechnology activities, they need access to local seed markets for product delivery. This leads to vertical market cooperation and integration. Many of the successful seed enterprises, especially in the USA, have already been acquired by agrochemical companies.

Obviously, horizontal and vertical market integration puts biotechnology firms in a position to pursue strategic R&D objectives. In the long run, however, too high a market concentration could also limit competition and thus depress rates of technological progress, with associated losses in social welfare. Already today, the lion’s share of the patents relevant for crop biotechnology is controlled by only a handful of multinational life-science companies

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² However, recent developments, such as Novartis’s announcement to split off the seed section from the mother firm, suggest that these research synergies might be smaller than initially expected.
their agricultural biotechnologies to the South. However, there are certain institutional obstacles limiting a widespread transfer of proprietary biotechnologies to developing countries.

Lack of suitable local partners. In many cases seed technologies need to be incorporated into locally adapted varieties before they can be used successfully. With biotechnology, the transfer of desired crop traits across varieties is generally much easier than it is with conventional tools of crossbreeding alone. But for technology adaptation and product positioning in local markets foreign firms require capable resident partner organizations, which are often not easily available.

Lack of IPR protection. IPRs are usually weak or are difficult to enforce in developing countries. This makes it an unfavorable environment for private business, especially in open-pollinated crops, because technology multiplication through farmers saving their once acquired seeds cannot be prevented. The TRIPs agreement will gradually lead to higher protection standards. Whether this will improve technology access for developing countries is still a matter of controversy. The disadvantage of strengthened IPRs are royalties that have to be paid when importing foreign technologies. Weak IPRs, on the other hand, provide a disincentive for private national R&D and can be associated with denied or delayed access to certain innovative technologies from abroad (cf. Lesser, 1997, p. 10). As there is scope for interpretation in the TRIPs agreement, the optimal IPR system should be identified for each country on a case-by-case basis.

Lack of regulatory mechanisms. The responsible application of modern agricultural biotechnology in a country requires that effective biosafety and food safety regulations are in place. Many developing countries lack the financial and human capacity to establish such regulations. Ill-defined regulatory mechanisms can lead to protracted processes of variety approval, which increases the risk for private business. In January 2000, a Protocol on Biosafety to the Convention on Biological Diversity has been adopted under the auspices of the United Nations Environment Program. The protocol foresees internationally uniform standards for the safe transfer, handling and use of genetically modified organisms. Without parallel biosafety capacity building at national levels, however, this protocol will rather constitute a further obstacle to international technology transfer.

Lack of public acceptance. Some non-governmental organizations are convinced that agricultural biotechnology is harmful for the developing world. Because of the international influence that these interest groups have, especially those from the North, the biotechnology opposition in some developing countries is also growing. As a result, national policy-makers are partly reluctant to support the technology. This makes it difficult for private firms to test and commercialize their innovations. For rational decisions, the flow of objective information is important, and the voices of the developing countries themselves need to be strengthened (Wambughu, 1999, p. 16).

These obstacles ought to be overcome in order to improve the absorptive capacity of developing countries within international transfers of proprietary biotechnologies. Yet a legitimate concern is whether private technologies will also benefit resource-poor farmers. From a mere industry point of view, it is quite understandable that biotechnology firms call for stringent IPRs, or that they try to incorporate genetic use restrictions into newly developed varieties. But the outcome would be a curtailment of small-scale farmers in their common practice to recycle seeds, which is undesirable on social grounds. This conflict reveals that the activities of the private sector alone will not suffice to ensure an equitable biotechnology evolution. The case studies in the previous section showed that, under certain circumstances (e.g., when the opportunity costs are low), companies are willing to donate proprietary biotechnologies for use in smallholder agriculture. Technology donations from the private sector should be exploited wherever possible. Nevertheless, it is unlikely that they will constitute the future model of technology transfer.

4.3 The Role of the Public Sector

Although the private sector can and should play an important role in providing biotechnology access to developing countries, there are remaining technology areas that will not be tackled by private research owing to market failures. One of the main causes of market failures in developing countries is poverty; lack of purchasing power prevents the translation of human needs into effective demand. Private technology efforts focus on domains with large market potentials so that R&D investments can be recovered and profits made. Many developing-country crops, notably typical semi-subsistence crops (e.g., starchy roots and tubers), do not provide sufficient incentives for private research engagement. Such crops are often termed ‘orphan commodities’. Likewise, certain traits that are of relevance primarily for poor producers and consumers will hardly attract commercial interest. Examples are crops well adapted to marginal agroecological environments or micronutrient-dense staple foods. Such private research gaps have to be identified and filled by public endeavors to make biotechnology innovations relevant for poverty reduction.

Within the last two decades, several biotechnology initiatives were founded, with the aim to link national and international research focusing on the needs of farmers and food...
consumers in the South. The International Program on Rice Biotechnology, funded by the Rockefeller Foundation, and the Cassava Biotechnology Network are prominent examples of such initiatives. Furthermore, public development-oriented biotechnology research is partly carried out by the centers of the Consultative Group on International Agricultural Research (CGIAR). However, the CGIAR recognized the big potentialities of biotechnology comparatively late, so related experience as well as biotechnology expenditures in the centers are still fairly low. Currently, the CGIAR spends some 30 million US$ per year on biotechnology, which is only about 8 percent of its overall resources. In total, the international donor community invests an estimated 75 million US$ per year in agricultural biotechnology. The developing countries spend approximately an additional amount of 125 million US$ from their own resources, so that the overall annual biotechnology expenditures with relevance to the South reach a level of around 200 million US$ (HORSTKOTTE-WESSELER and BYERLEE, 2000). This is a sizable sum; but it is negligible compared to the corresponding private-sector outlay. Monsanto alone devotes more than 500 million US$ per year to agricultural biotechnology research. The meaning of such a comparison is certainly limited. Nonetheless, it has to be stated that the present public investments are insufficient to capitalize on the big potentials of biotechnology to contribute to global food security.

In addition to financial constraints, however, there are also institutional shortcomings limiting the effectiveness of public biotechnology R&D. Isolated research niches for public research cannot be easily defined anymore, because basic biotechnology tools often apply to a diverse range of crops and problems. Given the concentration of patents in the corporate sector it would be difficult or impossible for public research to get access to the elementary tools without interacting with private companies. Therefore, public-private R&D partnerships have to be strengthened. A critical question is the ownership of technologies developed by public organizations partly on the basis of proprietary inputs. In the past, this was not always clarified before large public R&D investments were made (COHEN et al., 1999, p. 257). Insufficient agreements can lead to frustration and waste of resources as private companies may eventually block the release of emerging technology products.

Working with proprietary technology components requires careful contractual arrangements for each specific case, stating where, under what conditions, and for what purpose the technology might or might not be used by the license-taker. If such contractual arrangements cannot be ensured, private companies are understandably hesitant to license patented innovations to public institutes. Bilateral agreements between a company and a single developing country are much easier to negotiate than multilateral ones. Because of its global mandate and prevailing public good policy, for instance, the CGIAR centers find it difficult to get access to proprietary research tools and technologies for further adjustment and final release. Given the international exchange of germplasm, it could not be ruled out that the resulting public sector technologies with proprietary components would also be used in countries where the conditions for commercial technology releases by the patent-holding firms are favorable.

In the case of orphan commodities things are somewhat easier because private companies have no immediate commercial interest in these poor people’s crops. Biotechnology can provide the means for the transfer of genetic material across species, so that certain genes used by private firms in commercial crops could also be valuable for public R&D on orphan commodities. Apart from promoter or marker genes with a broad spectrum of possible applications, this holds true even for specific resistance genes when the relevant crop species are attacked by similar pests or diseases. If private companies can watch over their safe employment, there is no reason why they should not agree to license or even donate proprietary technologies for use in orphan commodities. The aforementioned sweetpotato project is a good case in point.

However, the design of appropriate IPR policies for broader inter-sectoral collaborations remains a challenging task for the CGIAR centers as well as for the national agricultural research systems. Harnessing the comparative advantages of the public and private sectors is a prerequisite for the efficient provision of highly beneficial biotechnology innovations to the poor.

5 Conclusion
The role of crop biotechnology for food security and poverty reduction should not be overrated. Many problems in low- and middle-income countries are not amenable to technological solutions. Yet biotechnology could contribute to sustainable development in two important respects. First, integrated into existing crop improvement programs biotechnology could increase agricultural productivity beyond what is possible with conventional breeding techniques alone. This would enhance the global food availability at affordable prices, while promoting environmentally sound production patterns. Second, appropriate biotechnologies could raise the revenues in agricultural production, which is still the dominant source of income and employment for the rural poor in large parts of the world.

The case studies from Kenya and Mexico underscore that biotechnology can bring about sizeable welfare gains for agricultural producers and consumers in developing countries. Although the development of modern biotechnologies can be quite demanding at the laboratory stage, this does not hold for the resulting end-technologies, viz. the genetically
engineered crop varieties that farmers deploy. Transgenic crops, especially those with resistance to biotic and abiotic stress factors, fit well into small-scale farming systems and can easily be integrated without adjusting traditional cropping practices. The comparatively low setup cost for adopting genetically engineered technologies at the farm level also makes this technology useful for semi-subsistence agriculture.

It must not be overlooked, however, that to date the industrialized countries dominate the research and application of biotechnology. Realizing the mentioned technology potentials for the developing world in a broader context remains a challenging task for policies at national and international levels. Apart from a limited number of innovative biotechnology transfer projects, the question of who will provide suitable technology products to the poor remains critical. Widespread market failures narrow the interests of private commercial technology suppliers. Public institutes, on the other hand, find it increasingly difficult to conduct independent research on account of the concentration of relevant patents in the private sector. Profound and pro-poor institutional adjustments in research and regulatory frameworks are essential to ensure that biotechnology does not bypass those who need it the most.

References
Figure 1: Distribution of global area planted to transgenic crops (1999)

Table 1: Potential economic surplus gains of transgenic technologies

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<tr>
<th>Virus-resistant sweetpotatoes in Kenya</th>
<th>Virus-resistant potatoes in Mexico</th>
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<td>Total annual gain (million US$)</td>
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<td>of which in %</td>
<td>30.3</td>
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Figure 2: Benefit distribution of transgenic potatoes in Mexico among different farm sizes