



Annex 6

Case study Transgenic crops

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STOA Project "Agricultural Technologies for Developing Countries

CASE STUDY: GENETICALLY MODIFIED PLANTS

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CHARACTERISTICS OF THE PRODUCTION SYSTEM 1.

Genetically modified – or transgenic – plants do not represent a homogeneous, distinct production system. The genetically engineered change to a plant variety may affect other elements of cultivation (e.g., plant protection or tillage) to very different degrees. Undoubtedly, developments in the area of intellectual property rights and the establishment of biosafety regimes can be regarded as the biggest "systemic" effects on agriculture overall, whereby different risk philosophies (e.g., in the USA and the EU) and national differences have a strong influence here.

Note: The following case study is based to a great extent on the results of the project "Transgenic seeds in developing countries" which the author completed in November 2008 on behalf of the German Parliament and in the name of TAB (TAB 2008). A summary of the report is available from www.tab.fzk.de, and an English version of the whole report is projected.

DEFINITION 1.1

The term "biotechnology" is often used in English in some measure as a synonym for "genetic engineering", although biotechnology also includes traditional procedures used in food processing and production, such as beer brewing, and modern methods that do not lead to the creation of genetically modified organisms. This usage is often criticised, but is in fact irrelevant if limited strictly to the implementation of genetically modified plants. These can be defined, for instance, as follows (FAO 2004, p. 8):

"Genetically modified (synonyms: transgenic or genetically engineered) plants are the products of using recombinant DNA techniques in plant breeding. Recombinant DNA techniques, also known as genetic engineering or (more familiarly but less accurately) genetic modification, refer to the modification of an organism's genetic make-up using transgenesis, in which DNA from one organism or cell (the transgene) is transferred to another without sexual reproduction. Genetically modified organisms (GMOs) are modified by the application of transgenesis or recombinant DNA technology, in which a transgene is incorporated into the host genome or a gene in the host genome is modified to change its level of expression."

KEY ELEMENTS 1.2

The basic element is the transgenic variety of plant and, depending on the kind of genetic modification, this may be supplemented by related production resources, and cultivation techniques or measures. As shown in Sect. 2, so far only two transgenic

traits are in actual use worldwide and thus also in developing countries, namely insect resistance (*IR*, as result of the transfer of *Bacillus thuringiensis* or "*Bt*" toxin genes) and herbicide resistance (*HR*).

The cultivation of any other genetically modified plants is only very limited and they thus play hardly any economic role (e.g., virus-resistant varieties or altered colours for decorative flowers) or are still at the development stage (crops resistant to abiotic stress such as drought or salinity; plants for the production of functional foods, pharmaceuticals and industrial chemicals, also called molecular farming) (see Sect. 4).

For insect-resistant varieties (and similarly fungal-resistant crops), a separate production resource (insecticide or fungicide) is integrated beforehand. This tends to reduce the steps necessary for cultivation. Additionally, specific actions to manage resistance can be prescribed such as setting up refuge areas (as is usually the case, though not, for instance, in China, TAB 2008).

HR crops are always associated with a defined production resource, namely the relevant herbicide, usually a broad-spectrum one that kills off most other plants. Depending on which cultivation method was previously employed, the changes can be great: often, for instance, ploughing is no longer required as a central component of weed management. As a result, as in the Argentinian Pampa, sowing time can be pushed so far forward that a second harvest per year is possible: before the use of ploughless cultivated HR soybean, it was necessary to wait for the wet winter weather to dry up enough to be able to drive onto the fields and plough them. HR soybean seeds, by contrast, can be sown directly into the ground while it is still damp. This explains to a large extent why transgenic soybean has become so widespread in Argentina.

In a wider sense, the necessary scientific, business, regulatory and administrative structures can also be understood as essential elements of the development, availability and implementation of genetically modified plants. These then include:

- > Competent and efficient research institutions, either public or private
- > A functioning system of seed production and distribution, including specific variety-protection systems,
- > Established regulation - specific to genetic engineering – of the licensing (research and marketing) of transgenic plants, including (efficient) risk management (in the face of resistance development and outcrossing) and monitoring,
- > If necessary, a system of coexistence, identity preservation and product separation.

KEY TECHNOLOGIES

1.3

With regard to key technologies, a distinction must also be made between the development and production of genetically modified plants as such and their cultivation and use.

It is a prerequisite for the development of genetically modified crops to establish the method of genetic engineering or transgenesis. As a scientific and methodological basis, a number of cellular and molecular biological techniques must be adopted and routinely performed. In order to transfer targeted genes, these must previously have been researched, described, isolated and available.

Many of the recombinant DNA techniques, some of them competing with each other, are patented and must be bought as licenses. The patents are mainly held by the large multinational agricultural biotech companies. Licensing is normally only possible in countries with advanced seed production and distribution systems, which include functioning variety protection and/or patent systems.

With a view to the requirements of biosafety and potential product separation in the cultivation and trade of genetically modified plants, it is necessary for the authorities to have efficient molecular diagnostic procedures and suitable analysis techniques for monitoring and control.

INVOLVED KNOWLEDGE

1.4

Recombinant DNA techniques are now actually a part of the standard repertoire in plant breeding and can thus also be used by countries and institutions that are not at the forefront of science and technology. For certain varieties of plant, however, there is still no simple transgenesis procedure so that here it is a question of real scientific innovations, i.e., a kind of high-tech or basic research at the foremost scientific frontier.

It is often urged that local or native knowledge should be taken into account or indeed have an influence in developing genetically modified plants, e.g., to define breeding aims tailored to the user and produce customized varieties. However, there are few reports of concrete examples.

Bt and HR varieties are mainly used in normal, conventional agricultural production systems, whereby an additional level of information must be calculated in/estimated for the necessary measures in risk management (including the designation of refuge areas to prevent resistance or the monitoring and – if necessary – control of secondary pests). But even in the highly developed agriculture of the industrial countries, the adherence to so-called Good Agricultural Practice, e.g., in the use of pesticides, can still not be taken for granted (and again and again leads to the application of unnecessarily large quantities). Worldwide, the WHO calculates there are over 350 000 deaths per year due to the incorrect application of pesticides (WHO 2003, according to World-bank 2007, p. 224).

A different case would be the cultivation of genetically modified plants for the purpose of molecular farming, i.e., the production of functional foods, pharmaceuticals and industrial chemicals. For this, special knowledge – and to some extent also special

technology – is necessary to stay abreast of the increased safety requirements and to rule out intermingling with normal harvests. However, it is not to be expected that genetically modified plants of this kind will be grown by small-scale farmers and traded freely on the markets; contractual cultivation with increased information complexity is far more likely to be in the active interest of the industrial client who wants to process the harvest products.

KEY ACTORS

1.5

Although research into genetically engineered breeding approaches may also be conducted in a decentralized fashion in publicly financed institutions and in smaller companies, the real development of genetically modified plants in fact predominantly takes place in a few large seed companies, many of the most important of these, first and foremost Monsanto but also Dupont/Pioneer, Syngenta, Bayer CropScience and BASF, are also important producers of agricultural chemicals. Locally, the large companies work together to some extent with resident seed companies in which they often have shares (if they have not taken them over altogether).

An important role in distribution is played by the governments and licensing and monitoring authorities involved according to their basic attitude to genetically modified plants and through the thoroughness and efficiency of their work.

In addition, in terms of acceptance by farmers, an important role is played by the nature and intensity of opposition movement to the use of genetically modified plants which is encountered in practically all countries. These often proceed from environmental organizations, globalization critics and representatives of small-scale farmers, the landless, and indigenous population groups. There are particularly strong opposition currents in Latin America (where there is also a particularly large amount of genetically modified plants grown, especially HR soybean), in India, and in some African countries. The authoritarian Chinese nation allows less leeway here.

As is the case for the whole general area of modern agricultural technology for and in developing countries, the Consultative Group on International Agricultural Research (CGIAR) and the International Agricultural Research Centres (IARC) also play an important role in the development of genetically modified plants (see Background Paper "Context of Agricultural Technologies for Developing Countries"; Meyer 2008, p. 32 ff).

The research centres are mainly located in developing countries, are legally autonomous institutions and focus on particular plant varieties or research fields. For varieties such as cassava, sorghum, sweet potatoes, plantains or diverse legumes, whose only role is to provide food in developing countries, the IARC are often the only ones to follow up more recent research approaches and methods. On the one hand, the coun-

tries cultivating the crops are in no position to finance this research, and on the other hand, the large seed companies have no interest in these plants.

The use of genebanks is a central task of 11 of the 25 centres as the basis for breeding research and breeding. The focus is on conventional approaches, and modern, marker-supported selection procedures ("smart breeding"); research on transgenic plants is also supported. About 7% (smart breeding) and 3% (transgenic approaches) of the research projects concentrate on the latter (<http://www.cgiar.org>; data for 2005). Conventional varieties were developed in great numbers in the past decades (most recently including more robust rice and drought-tolerant maize varieties for Africa), but not a single variety modified by genetic engineering has yet been developed to market maturity. The most advanced project here too is "Golden Rice" (see Sect. 4.2), in the development of which the International Rice Research Institute (IRRI) contributed.

Two of the four current, cross-centre programs, so-called challenge programs, are based on the use of molecular biological methods from plant breeding: one to improve the supply of micronutrients ("HarvestPlus", see below) and one for the molecular characterization of genetic resources. But also in the framework of the two other projects – to improve the agricultural use of water and on integrated agricultural development support in sub-Saharan Africa – plant breeding plays a role (<http://www.cgiar.org>).

INTERNATIONAL COOPERATION

1.6

A specific development cooperation to develop genetically modified plants is not (or at least only in individual cases) supported in bilateral projects by Germany (and many other EU countries, but above all by support of the IARCs). The USA acts differently here and supports the use of genetically modified plants in general as well as the large projects of the Gates Foundation via the USDA and various development cooperation organizations (see Sect. 4).

The most comprehensive international cooperation projects come from the commitments of the Convention on Biological Diversity and in particular the International Protocol on Biosafety, known in short as the Cartagena Protocol after the conference location in Cartagena, Colombia. This international agreement represents the first binding regulation in international law of the handling of genetically modified organisms and came into effect in 2003. The objective of the Cartagena protocol "is to contribute to ensuring an adequate level of protection in the field of the safe transfer, handling and use of living modified organisms resulting from modern biotechnology that may have adverse effects on the conservation and sustainable use of biological diversity, taking also into account risks to human health, and specifically focusing on transboundary movements." (<http://www.cbd.int/biosafety/articles.shtml?a=cpb-01>)

The "Biosafety Unit" of the UN Environmental Program and the Global Environment Facility (GEF) set up by the UN and the World Bank and supported by over 170 states (to promote globally relevant environmental projects in developing countries) is additionally currently supporting 19 countries in the implementation of pertinent sets of regulations and 139 countries in establishing capacities for taking part in the so-called Biosafety Clearing House (BCH) as a central contact and information mechanism for putting the stipulations of the Cartagena Protocol into practice (<http://www.unep.org/biosafety/>).

The German Ministry for Economic Cooperation and Development, for instance, supports the establishment of capacities for assessing the risks of genetic engineering in the framework of the German Biosafety Capacity Building Initiative, for instance, by supporting the African Model Law on Biosafety, which the African Union developed in 2001 as a guiding framework and starting point for national regulations by its member states.

POTENTIALS FOR SUSTAINABILITY

1.7

This is a central and fundamental point of contention in the debate on genetically modified plants. Several subpoints (of contention) can be distinguished:

- > *The question of the basic concept constituting sustainability:* Basically, in most countries there is no clear and practicable concept for setting in motion a scientific, social and political agreement over the aims, strategies and channels of sustainable agriculture – this is also true for the industrial countries.
- > *The question of how the various effects of using Bt and HR plants really look:* Basically the problem exists that there are many diverse influences on the possible benefit in the sense of harvest yield and resulting profit to be derived from using transgenic seeds, e.g., by the cultivation technique currently or previously used, by the intensity of pests, by strong fluctuations in seed prices, and by competing varieties, to name but a few. The influence of the individual factors on the overall yield is extremely interpretable in most cases.
- > *The question of how these should be evaluated:* An evaluation of the environmental effects of HR varieties, for example, appears highly complex as there are varied and indirect effects emanating from their implementation on the cultivation technique (reduction in tillage, fuel savings) and land use (crop rotations, increased acreage). These would have to be considered in the framework of a comprehensive impact assessment and evaluation in addition to the "direct" effects of the herbicides used and saved on humans and the environment and be weighed against these. To carry out a higher-level evaluation, it would be necessary to include a weighting as to which legally protected goods (e.g., health, soil fertility, biological diversity, CO₂ emissions, rural development, resource distribution) have priority (which in turn can only be inferred from the developmental aims of a region or a country) and what

contribution can be provided here by genetically modified varieties compared with alternative options

Actors in European development cooperation (in Germany, for example, also in national development cooperation) mainly doubt that genetically modified plants can contribute to sustainable agriculture, but the USA thinks differently. The international voice of opposition to the use of transgenic seeds are Friends of the Earth International (see FOEI 2007), while the strong voice in their favour is the International Service for the Acquisition of Agri-Biotech Applications (ISAAA) (see James 2007).

The World Bank (2007), FAO (2004) and the Nuffield Council on Bioethics (2003) regard the potential of GMP for sustainable agriculture as given, but rely on very weak data or scenario projections (TAB 2008, p. 230 ff, p. 261 ff) The IAASTD (2008) is much more sceptical (see Background Paper "Context of Agricultural Technologies for Developing Countries"; Meyer 2008, p. 71).

The TAB report concludes that a potential evaluation on the basis of the available information is not possible and argues for an examination of the options without pre-determining the results and with a view to finding solutions (TAB 2008, p. 261 ff; see Sect. 7).

KEY RESTRICTIONS / UNUSED POTENTIALS

1.8

Questions of unused potentials and underlying restrictions are highly controversial among scientists and stakeholders. Proponents point out regulations that are – from their point of view – too strict and resulting costs which prohibit the development of adapted genetically modified varieties for developing countries.

However, regardless of the preferred biosafety philosophy ("precautionary or not"), the establishment and implementation of an effective regulatory system represents a major problem for many countries. The fact that in many or indeed most developing and emerging countries there has been a great deficit for years in the institutions for risk evaluation and regulation can be taken as a consensus in the debate (Johnston et al. 2008)

Another consensus (related to the first stage of the innovation process including genetically modified plants) concerns the fact that overall funding for agricultural research and development in general as well as specifically for plant breeding - including genetic engineering - has been much too low in recent years (cf. Background Paper "Context of Agricultural Technologies for Developing Countries"; Meyer 2008, p. 36 f.).

The undeniable result of this meagre funding is the fact that worldwide cultivation is restricted to four of the most important (cash) crops (see Sect. 2), because for understandable economic reasons the research and development work of the dominant seed

companies can hardly be orientated to plant varieties which might be specifically relevant for small-scale farmers in developing countries (such as cassava, sweet potatoes, etc., see Sect. 4).

At the level of distribution of existing transgenic varieties, restrictions may proceed from insufficiently developed seed markets, which is still true for many of the poorer developing countries. This restriction is, however, not specific to genetically modified plants in the stricter sense but applies to all varieties of protected and traded (high-performance) varieties.

In the past few years, the lack of customized varieties for developing countries has been a regular topic. The reasons given were that for seed companies the market segments were often too unattractive from an economic point of view. This is, however, no longer applicable to the large growing nations – here the genetically modified traits are now available in more diverse varieties (following the use of suboptimal basic varieties in the first few years).

A further obstacle may consist in a licensing restriction for the EU market if varieties that are licensed and grown in a developing country do not possess an EU licence. However, this is as yet still purely theoretical since no so-called asynchronous approvals currently exist although they have been increasingly feared and discussed in the past few years.

However, varieties that are approved in the EU may also encounter consumer rejection in the food sector and thus destroy the export opportunities for developing countries. This has so far not been a problem for the HR soybean and Bt cotton grown predominantly so far (see Sect. 2.3) since consumers are far less sensitive in the animal feed sector and only negligibly in the textile sector.

INTERRELATIONS WITH OTHER PRODUCTION SYSTEMS 1.9

At first sight, the impression might be given that HR crops represent an essential requirement of no-till farming and are thus an integral component of conservation agriculture systems, at least in countries like the U.S. or Argentina, where their use is widespread. But as the case study on conservation agriculture by Friedrich et al. (2009) shows, this is not the case, since no-till farming and conservation agriculture were being practised long before the existence of genetically modified organisms. And even more important, conservation agriculture in a comprehensive sense comprises much more than no-till plus herbicide. In complete contrast to the common promotion by supporters of genetically modified HR technology, according to Friedrich et al., the no-till farmers organizations dedicated to conservation agriculture in the above-mentioned countries discourage the HR farming method. The reason is that it is frequently used to grow only one crop (soybean or maize) in an continuous monoculture and in most

cases leads to herbicide resistance, pest and disease problems, environmental and human health deterioration, and other difficulties (Friedrich et al. 2009, Sect. 1.9.6).

There is obviously a very clear and simple interrelation between genetically modified plants and organic agriculture: the latter excludes the use of the former – according to the worldwide rules in force by the International Federation of Organic Agricultural Movements (IFOAM; see case study on organic agriculture: Hoffmann 2009).

Specific interrelations of genetically modified plants with rain water harvesting or agroforestry systems are not visible except for those with other (conventional) agriculture in general: At least in Europe, where the intention is to permanently establish a strict regime of coexistence between genetically modified crop cultivation and conventional (and organic) farming, specific rules and measures to prevent the intermingling of genetically modified and other agricultural products have been set up. Farmers in developing countries, who want to export their products to the EU, basically have to follow the rules of declaration. If they want to guarantee genetically modified plant-free products, they must establish identity preservation systems which document their entire production chain.

CURRENT RELEVANCE / BASIC DATA ON USE 2.

The data source most often cited on the worldwide distribution of genetically modified plant cultivation are the annual reports of the International Service for the Acquisition of Agri-Biotech Applications (ISAAA) ¹ entitled "Global Status of Commercialized Biotech/GM Crops" (latest versions James 2006, 2007). The areas given here are either from surveys or reports from agricultural authorities or associations or projected from seed sales². The following data are also based on this source.

GLOBAL AREA 2.1

In 2007, the estimated global area of genetically modified crops was around 114 million hectares (representing approx. 5% of arable land worldwide). Genetically modified crops were grown in 23 countries (James 2007). Twelve years after the commercial introduction of transgenic plants, there are still only two genetic traits (herbicide tolerance and/or insect resistance) and four crops that represent more than 99% of the

¹ The ISAAA describes itself as a non-profit-making organization for the promotion of genetic engineering in agriculture in developing countries. It is backed by the large seed companies that work with genetic engineering as well as a number of foundations that are well-disposed towards genetic engineering. In addition, it receives support from development organizations particularly in the USA (www.isaaa.org).

² The numbers are sometimes criticized as inaccurate (FOEI 2007, p.7 f.), but their size is not seriously disputed.

acreage: soybean (51%), maize (31%), cotton (13%) and rapeseed/canola (5%). The global area of genetically modified crops has grown continually, including in some important emerging countries. A total of 88% of the genetically modified plant acreage is located in North and South American countries.

AREA IN DEVELOPING COUNTRIES

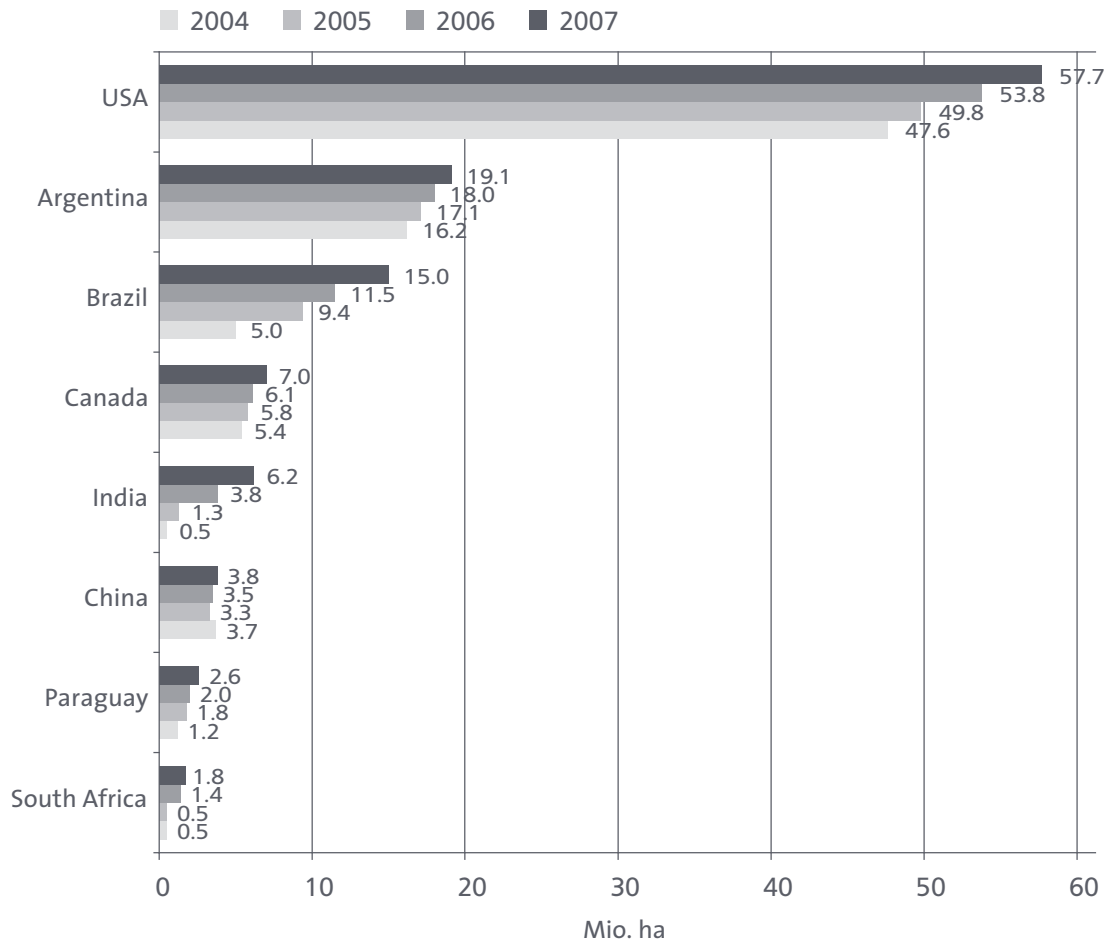
2.2

The country with the largest area of genetically modified crops is the USA with 57.7 million hectares, representing half of the total global area. The next nine countries include eight developing nations (values for 2007 from James 2007): Argentina (19.1 million hectares), Brazil (15.0 million hectares), Canada (7.0 million hectares), India (6.2 million hectares), China (3.8 million hectares), Paraguay (2.6 million hectares), South Africa (1.8 million hectares), Uruguay (0.5 million hectares) and the Philippines (0.3 million hectares).

Figure 1 shows the development from 2004 to 2007 in eight countries with the largest area of genetically modified crops, representing 98% of worldwide genetically modified plant acreage. The increase during this period was moderate in the U.S., Argentina and Canada, while all the other countries, except China, showed a steep rise, e.g., Brazil and Paraguay from 2004 to 2005 and from 2006 to 2007, India from 2005 to 2007, and South Africa from 2005 to 2006.

China was the only country where there was a decrease (from 2004 to 2005). This is explained by the appearance of a secondary cotton pest that could not be controlled using insect-resistant Bt varieties.

FIGURE 1 COUNTRIES WITH THE LARGEST AREA OF GENETICALLY MODIFIED CROPS



Source: James 2004, 2005, 2006, and 2007

DISTRIBUTION OF CROPS AND CHARACTERISTICS 2.3

Table 1 provides an overview of plant varieties, genetic traits and acreage shares (as a percentage of the overall area of genetically modified crops and of the area for that particular crop) of transgenic plants in the ten countries with the largest areas for 2007.

TABLE 1 GENETICALLY MODIFIED CROPS 2007: ACREAGES, TRAITS, PERCENTAGES

Country: Genetically modified crop acreage (2007) in million hectares	Crop	Percentage of all GMP crops	Transgenic feature (trait)*	Percentage of genetically modified acreage compared with overall crop acreage
USA: 57.7	Maize	50%	HR, Bt, HR+Bt	77%
	Soybean	41%	HR	94%
	Cotton	no data	HR, Bt, HR+Bt	93%
	Rapeseed	no data	HR	82%
Argentina: 19.1	Soybean	85%	HR	99%
	Maize	no data	Bt, HR	70%
	Cotton	no data	Bt, HR	95%
Brazil: 15.0	Soybean	96%	HR	64%
	Cotton	4%	Bt	50%
Canada: 7.0	Rapeseed	75%	HR	87%
	Maize	no data	HR, Bt, HR+Bt	85%
	Soybean	no data	HR	62%
India: 6.2	Cotton	100%	Bt	66%
China: 3.8	Cotton	100%	Bt	69%
Paraguay: 2.6	Soybean	100%	HR	94%]
South Africa: 1.8	Maize	> 85%	HR, Bt	57%
	Soybean	no data	HR	80%
	Cotton	no data	HR, Bt, HR+Bt	90%
Uruguay: 0.5	Soybean	87%	HR	100%
	Maize	13%	Bt	45%
Philippines: 0.3	Maize	100%	HR, Bt, HR+Bt	10%

* HR: herbicide resistance, Bt: *Bacillus thuringiensis* insect resistance; HR+Bt: both ("stacked events")

Source: Author's own compilation according to James (2007)

In the developing and emerging countries, it is clear that the crops grown on most areas are HR soybean (in 2007 there were about 33 million hectares in Argentina, Brazil and Paraguay) and Bt cotton (in 2007 there were a good 10 million hectares primarily in India and China). Only in South Africa and in the Philippines is maize the dominant crop from transgenic seeds and is used for fodder and as an important basic foodstuff. Transgenic cotton is grown (HR, Bt, HR+Bt) in Mexico (115 000 hectares) and Colombia (22 000 hectares) too (James 2007). In Chile and Costa Rica, transgenic varie-

ties are grown on behalf of seed companies for propagation (TAB 2008). Since 2008, it has been permitted for Bt cotton to be grown in Burkina Faso, and Bt maize in Egypt (CropBiotech Update 2008 and Sawahel 2008, from Felkl 2008).

Both cotton and soybean are grown as so-called "cash crops"³, mostly for export and to some extent for processing in local industry, e.g. Bt cotton in China. Soybean is traded primarily as a (particularly protein-rich) fodder but also as a foodstuff, primarily in the form of cooking oil. This means soybean is one of the most intensely traded agricultural products. It supplies two-thirds of the world's requirement in protein-rich flour, and one-third of the global need for cooking oil (Grenz et al. 2007). In the future, the production of biodiesel fuel from soybean could increase in importance. The world's largest producers and exporters are Argentina, Brazil and the USA. Brazil, in particular, plans to extend its cultivation acreages tremendously.

Although cotton is grown on relatively small acreages (35 million hectares, approx. 2.4% of the worldwide acreage) in comparison to maize, rice, wheat and soybean, and accordingly harvested in smaller quantities (24 million tonnes, of which a good 6 million tonnes are traded internationally), it is by far the most important non-food-plant. For instance in China, due to its comparatively high price, cotton is most important agricultural product overall in terms of value. In Brazil, the central agricultural product is soybean, with a share of about 10% of the country's total export, and in 2007 about two-thirds of it was produced using transgenic varieties.

DISTRIBUTION ACROSS FARM TYPES 2.4

These few numbers suffice to show that transgenic seeds have so far been almost exclusively cultivated as cash crops in developing and emerging countries. The crops are grown by an increasing number of small-scale farmers. It is estimated that in 2007, Bt cotton was grown in China by 7.1 million small-scale farmers and in India by 3.8 million of them (James 2007, p. 107). Cultivation for the purpose of food security or local markets, by contrast, seems to be marginal. In Asia, which is by far the most densely populated continent, for instance, in 2007 (according to the ISAAA) it was only in the Philippines that transgenic maize was grown by approximately 125 000 small-scale farmers as a foodstuff on 250 000 hectares. This is rather a modest proportion of the approximately 47 million hectares of overall maize acreage in Asia (James 2007, p. 69). In addition, the data from the ISAAA are criticised by non-governmental organizations in the Philippines as being three to four times too high on the basis of the available data for seed sales (Plantanilla 2008).

³ The term "cash crops" is used to designate agricultural products that are produced in similar quality and large quantities for re-sale, often for industrial processing, and which are traded in unprocessed form or with only minimal processing on international agricultural exchanges.

The situation in Argentina illustrates the potential problems in interpreting economic and agricultural data: Friends of the Earth International (FOEI 2006, p. 31) with reference to Pengue (2005) underline that cultivation of HR soybean accelerated concentration after the number of businesses in the Argentinian Pampa had sunk from 170 000 to 116 000 in the 1990s and at the same time, the average size of them had doubled (i.e., there was also an increase in acreage).

Trigo and Cap (2006, p. 30 ff.) by contrast see no such effect. They concentrate on the distribution of the sizes of those businesses which grow (HR) soybean and demonstrate a markedly larger proportion of the soybean acreage in smaller businesses. This was, however, not caused by the introduction of HR soybean, but was already present beforehand.

In an international comparison, it must also be taken into consideration that in Argentina one must consider entirely different business dimensions than, for instance, in China or India (where the average size is 1 or 2 hectares). The areas given by Trigo and Cap (2006) are divided in 100-hectare steps, i.e., farms with up to 100 hectares are considered to be "small" businesses, while "really large" businesses have acreages that are in some cases well over 1000 hectares.

LIMITATIONS ON THE GENERAL FRAMEWORK 3.

FINANCIAL AND KNOWLEDGE RESOURCES 3.1

With regard to the development of transgenic plants for the particular benefit of agriculture in developing countries, proponents of a stronger use of genetically modified crops emphasize that regulatory and administrative licensing and cultivation conditions in connection with continually inadequate capacities in science administration have prevented further successes in development. It is indisputable that, regardless of type and implementation, specific regulation of transgenic plants makes their research and development more expensive than that of non-transgenic, conventional plants or varieties, and this is an obstacle in any case.

Basically, genetically modified varieties compete with other high-performance varieties, and thus their price in any case precludes their use by small-scale subsistence farmers with low resources. The genetically modified varieties are usually more expensive than conventional varieties because they contain an added value for the farmers: in the case of Bt varieties, this is the integrated insecticide, in the case of HR crops it is a component for weed management.

Thus even greater resources are bound up with them than with other high-performance seeds. For Bt varieties, this is worth it, particularly if the pressure of infestation is great and remains so. The problematic cases are those in which the financial situation of the

farmers just barely permits them to buy (high) performance seeds, but uses a larger portion of the resources than would otherwise be the case because of the higher price of the genetically modified varieties; the purchase then proves with hindsight to have been a bad investment, e.g., because a change in the occurrence of pests makes it necessary to use additional insecticides, as has been reported in China (Huang et al. 2007; TAB 2008, p. 104 f). Bt varieties require, for instance, very careful cultivation management, which, e.g. includes the designation of refuge areas to prevent resistance or the observation and if necessary control of secondary pests. Particularly in businesses with low capital, there is a danger that necessary measures are not carried out or not sufficiently carried out for reasons of cost.

Just as with handling pesticides, comprehensive clarification by the suppliers and agricultural services is necessary. Particularly because Bt varieties contain an efficient protection against specific pests which is paid for in the extra price of the seeds, they should only be used if – on the basis of complete information - their real qualities, their claims and their limits can be competently assessed in relation to the operating conditions. And in this regard, there are almost certainly deficits in the actual diffusion in developing and emerging countries in the promotion and distribution of Bt varieties. The presentation which is frequently reported of seeds which "contain all the technology for a higher yield and more environmentally friendly cultivation" is inappropriate and misleading and, particularly for financially vulnerable users, potentially dangerous.

It is not just the case in the use of transgenic varieties, but also and in particular in the production of food that is explicitly free of genetic modification, that a vulnerable financial situation represents a problem since the guidelines of the necessary systems of coexistence, identity preservation and product separation make investments necessary.

INPUT AVAILABILITY, INPUT PRICES

3.2

Basically, a functioning system of seed production and distribution, including specific variety-protection systems, is necessary for the supply of transgenic varieties. Intensive promotion and distribution, for instance of Bt varieties to small-scale farmers in India, is carried out by the supplier, Monsanto, and its local cooperation companies. Here critical voices regularly complain that the influence on the farmers' decisions is too strong. In some cases, there seems to be close cooperation between public offices and private companies in establishing and disseminating transgenic varieties, e.g., in South Africa .

HR crops represent an absolutely paradigmatic example of a combination of two production resources: seeds and herbicides. This results in linking the farmers in a particularly strong way to the relevant supplier, who usually distributes both as a package. The supplier – here too the most prominent example is Monsanto and its RoundupReady varieties and the herbicide Glyphosate – then has two linked products

which it can use for pricing. According to the situation on the seed market, the yields are obtained either primarily through the transgenic varieties or through the herbicide price. In Argentina, for instance, Monsanto made no money from the sale of the first generation of RoundupReady soybean varieties, but allowed them to be distributed licence-free by local seed companies. In addition to the strategic aim of achieving acceptance on the global fodder market through widespread cultivation in Argentina, Monsanto could also generate concrete profits by selling Glyphosate (FOEI 2006).

In the past few years, it could be observed that the price of Glyphosate greatly increased, which apparently led to a significant deterioration of the business balance sheet for the farmers (also in the USA; The Organic & Non-GMO Report 2008). The fact that the farmers still do not refrain from using the HR varieties so easily (even if this is by all means observable) is down to the fact that – as described in Sect. 1.2 – the use of HR varieties are bound up with extensive changes in the production systems.

One of the most important trends in the past few years in the field of transgenic varieties is the increasing combination of various Bt and HR traits in one variety, so-called stacked genes. On the one hand this is a reaction to the increasing resistance to individual herbicides, but also increases once again the added value, the price and attachment to the supplier.

LAND RIGHTS, LAND OWNERSHIP

3.3

As long as the transgenic variety requires a decision to be made again every year, there is hardly any specific connection to land rights or land ownership. However, the case could arise that a tenant would like to cultivate a transgenic variety but the land owner refuses this on principle. Such cases have come to light in Europe.

The question of land ownership can play more of a role where the changes in cultivation methods are more extensive, e.g., as a result of using HR varieties. In principle, it is easier for a land owner to make more long-term strategic decisions.

The size of farm plays an important role, for instance in guaranteeing a clearance area around transgenic acreage, less when transgenic varieties are used, but when their use is specifically undesired, e.g. to produce food that is explicitly free of genetic engineering.

AVAILABILITY OF MARKETS, AGRICULTURAL PRODUCT PRICES

3.4

The dominant transgenic varieties up to now, namely Bt cotton and HR soybean are cultivated as cash crops but not to supply the growers themselves or the local food

markets. For cash crops, there is by definition an (international) market but this is often not accessible to small-scale farmers.

Bt cotton in China and India represents an example of a cash crop, which is grown by small-scale farmers, while HR soja in South America is predominantly grown by large farms or by cooperatives of medium-scale farmers.

The higher investment costs for transgenic seeds make the businesses more susceptible to price fluctuations. Yield advantages as a result of more efficient pest control or cost savings through HR varieties can easily be cancelled out through a drop in price in cash crops traded on the global market. Examples of this have been reported from Brazil (HR soybean) and India (Bt cotton). The volatile nature of agricultural prices in 2008 made it clear once again how delicate a matter it can be for agricultural businesses to supply a single product. A product which might be especially susceptible in the future could be energy crops since their sale is particularly strongly affected by political decisions, as also shown in 2008.

In the future, novel genetically modified crops such as those for the molecular farming of functional foods, pharmaceuticals and industrial chemicals, will probably not be traded freely on the markets, but on the basis of contractual purchasing.

POLITICAL SYSTEM, CORRUPTION

3.5

The regulation of licensing and use of transgenic varieties is a specific, so that in comparison to other agricultural technologies the political and administrative system has a particularly strong influence on the establishment and spread of the use of genetically modified crops. The deficiencies in the area of biosafety and regulation in many developing countries are a central topic in the worldwide debate, and their removal is a central task for the future (see Sect. 7.1).

Critics find fault again and again with what they see as the inappropriately large influence of the seed industry and especially the international biotech companies on the political and administrative systems. Whether this means the usual kinds of lobbying or of unlawful exertion of influence or even bribery and corruption can only be evaluated in each individual case.

Brazil provides a specific, well-documented case of retroactive political legitimation of long-term unlawful use of unlicensed varieties. For years, transgenic seeds produced by Monsanto that came from Argentina were cultivated illegally on a large scale. This cultivation was legalized in a highly controversial, lengthy trial, through which the Brazilian government gave up the country's status as a major producer without genetic engineering (particularly for soybeans for the European market; Rehaag et al. in TAB 2008, p. 137 ff).

CONVENTIONAL AND NOVEL BREEDING AIMS: SUITABILITY AND PROSPECTS OF GENETIC ENGINEERING APPROACHES4.1

The three main aims of (classical) plant breeding are *yield increase*, *yield security* (i.e., resistance or tolerance to influences that jeopardize the yield such as pests and diseases or abiotic stress factors such as drought, salinity and heat) and the relevant *quality characteristics* (contents). In the public debate, there is often no distinction made – quite understandably – between the aims and the effects of increasing the yield (in the sense used in plant breeding) and those of securing the yield using more resistant plants. The result in each case is similar, i.e., a higher yield over several years, but yield security and stability is the more important survival parameter, especially for poorer farmers.

The *crop yield*, both of individual parts (infructescence, seeds, tubers, roots) and of the plant as a whole, is determined multifactorially as a complex feature and has so far offered little access to the influence of genetic engineering. Gene loci with a strong effect on quantitative features, so-called quantitative trait loci, (QTL) have so far been primarily used for innovative "conventional" breeding by employing corresponding molecular-genetic DNA markers (also known as "smart breeding"). So-called metabolic engineering for the transfer or regulation of entire metabolic pathways with the aid of genetic engineering is still at rather early stages of development (TAB 2005).

Improving plants' resistance to influences that reduce yield or quality – such as diseases and pests or lack of nutrients and water, i.e., corresponding resistance or tolerance, can be provided to some extent by single or just a small number of characteristics (genes or proteins) and can thus be in principle accessed by genetic engineering. The varieties cultivated so far with transgenic insect and herbicide resistance belong in this category, as do virus- and fungal-resistant varieties. The latter have been the subject of intensive research for many years due to the great relevance of fungal and viral diseases (e.g., in cereals, potatoes, fruit and vegetables). Only a handful of virus-resistant varieties have so far been approved and grown on restricted areas, e.g., peppers and tomatoes in China, pumpkin and papaya in the USA (James 2007). Similarly, resistance or tolerance to cold, drought, or salinity that can be used by genetic engineering has also long been the subject of research. In the course of the intensified debate on the future of world agriculture that has been going on since early 2008, several companies have emphasized that current and future research and development work is now concentrating particularly on varieties offering a higher yield due to better drought tolerance or nitrogen utilization, or on increasing yield in the strict sense under normal conditions. Since this focus was only implemented a short time ago, most of the develop-

ment projects are at such an early stage that it is impossible at the moment to assess their chances of success (Sprenger 2008).

The cultivation features optimized with regard to increasing and securing the crop yield – also known as agronomic features – stand against the quality characteristics of plants. Breeding efforts in this direction concentrate on the optimization of those parts of the plants which are used by the processors and consumers. This is particularly true for the composition of their ingredients, which determine taste, health value or technical processability. Since there are so many plant substances that are used so diversely in foodstuffs and fodder, as renewable raw materials or in energy utilization, the range of genetically engineered breeding efforts is extremely large, but there has as yet been no significant concrete use. See TAB (2005) for an extensive portrayal of this. The developments discussed there, for instance in the field of "functional food", "plant-made industrials" or "plant-made pharmaceuticals" do not reveal many aspects specific to developing countries with the exception of the biofortification approach, i.e., (genetically engineered) enrichment of basic foodstuffs with vitamins or essential minerals. Projects of this nature are being pursued for the target group of poor populations in Africa and Asia (see box).

FOUR TRANSGENIC "SUPERPLANTS" TO COMBAT MALNUTRITION – ONE OF THE GRAND CHALLENGES IN GLOBAL HEALTH

Four large genetic engineering breeding projects are being supported by the Bill and Melinda Gates Foundation – not as part of the support for agricultural development but for global health. One of the 14 challenges among the "Grand Challenges in Global Health" initiative, which was defined by an international scientific board and started in 2003 in cooperation with the American health authorities, the National Institutes of Health (NIH), is as follows: "*Create a full range of optimal, bioavailable nutrients in a single staple plant species*" (also known as biofortification). The aim is to provide poor populations in developing countries whose nutrition is strongly based on a single staple foodstuff - and who thus often have no guaranteed comprehensive supply of nutrients - with an enriched form of this staple food. With the aid of genetic engineering methods, the protein, vitamin A, vitamin E, iron, zinc, and selenium content of four plants specific to and relevant for developing countries should be increased or optimized. These plants are rice (funding: 11.3 million US\$), cassava (7.5 million US\$), sorghum (16.9 million US\$) and bananas (1.1 million US\$; data from 2007).

The rice project is based on "Golden Rice" (see below) which has already been developed quite a long way. The associated consortium ProVitaMinRice is headed by P. Beyer from the University of Freiburg, one of the "Golden Rice inventors". The International Rice Research Institute (IRRI) from the IARC is a participant, as are various bodies in the USA, Australia, the Philippines, Vietnam and China.

The "BioCassava Plus" project led by the University of Ohio is concerned with the starchy bulbous root known as manioc or tapioca which originated in South America and is cultivated there as well as in Africa and Asia. Cassava is considered the fourth most important crop in the world and is the staple food of up to 1 billion people. In particular, it is the main source of nourishment for more than 250 million inhabitants of the sub-Saharan African countries. In addition to biofortification, there are some breeding aims directed at producing viral resistance and a reduction in prussic acid – both have been pursued for many years (Katz et al. 1996, p. 150). The first release experiments were started in Puerto Rico. The cooperation partners are the International Institute of Tropical Agriculture (IITA) in Nigeria and further bodies in Nigeria, Kenya, Puerto Rico, Tanzania, Switzerland, Great Britain and the USA.

Sorghum, a type of millet, is the main foodstuff for more than 300 million people in the arid and semi-arid regions of Africa, but is also used as animal fodder in the USA (including for export to Europe) and has been grown on a trial basis in Europe for producing bioenergy (TAB 2007). The project, known until recently as "Supersorghum" and now as "Biosorghum (of *Africa Biofortified Sorghum*, ABS), is being handled by a consortium of nine institutions headed by the Africa Harvest Biotech Foundation International (AHBFI) in Kenya [the other members are International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); African Agricultural Technology Foundation (AATF); University of California, Berkley, USA; University of Pretoria (UP), Council for Science and Industrial Research (CSIR), Agricultural Research Council, all from the Republic of South Africa]. Greenhouse trials with bio-fortified sorghum lines were approved in South Africa in the late summer of 2008.

The (significantly smaller) transgenic banana project is being followed up mainly by three partners from Australia, Uganda and the USA and is primarily concerned with improving efficiency in gene transfer as such in bananas. Release trials are planned in Australia.

Sources: <http://www.gcgh.org>; <http://biosorghum.org>

It is undisputed that there are strictly speaking hardly any transgenic varieties specific to developing countries. What do exist are adapted HR and Bt varieties, mostly as a result of crossbreeding with regional varieties. China is to date the only developing or emerging country which has pursued its own true developments in genetic engineering to the level of approval and marketing. The number and variety of R&D projects on transgenic plants with particular benefits for agriculture in developing countries was and still is high overall – in the affected countries, in the international agricultural research centres (IARC, see Sect. 1.5), and in some cases in cooperation with institutions in industrial countries, but they continue apparently to be mainly at early stages and hard to assess. "Golden Rice" is considered to be the most advanced, best-known and possibly most significant breeding effort specific to developing countries (see below).

Regarding the problem of licensing issues or as a model to overcome these, so-called public private partnership projects have appeared increasingly in the past few years. Here the technology owners provide publicly financed research institutions with their patented, genetically engineered applications or varieties licence-free for particular aims. This procedure is an important basis of the projects described above (see box) which are currently the most comprehensive in the development of transgenic plants in international development cooperation and funded by the Bill and Melinda Gates Foundation.

"Golden Rice" has played a prominent role for years in both the general and developing country-specific debate on the benefits and consequences of green biotech (TAB 2005, p. 87 ff). Thanks to various genetically engineered changes, this rice has been given the ability to synthesize beta-carotene, the precursor of vitamin A. It is projected to supply the rice as a staple food in countries where there is vitamin A deficiency. Proponents of green biotech consider the project a prime example of the benefits of green biotech while critics see Golden Rice as a Trojan horse for the introduction of green biotech in developing countries and as an inadequate means of relieving the problem of vitamin A deficiency (see e.g., Greenpeace 2005).

VITAMIN A DEFICIENCY: CONSEQUENCES, PREVALENCE, CONTROL

Vitamin A is essential for sight, functions of the immune system, and growth and development in children. Vitamin A deficiency can lead to loss of sight in children and to increased mortality, since infectious diseases such as diarrhoea or measles can run a more serious course. According to data from the World Health Organization (WHO), vitamin A deficiency affects about 120 million children aged 5 years and under in 118 countries worldwide, particularly in the poor countries of Africa and South-East Asia.

Every year, up to 500000 children lose their sight as a result of vitamin A deficiency. About half of these die within 12 months or become permanently blind. In adults, vitamin A deficiency can lead to night blindness and reduce the body's defence to infections. An imbalanced diet – mainly due to poverty – e.g., mainly using polished rice, provides too little vitamin A or beta-carotene. As well as children, pregnant women are also particularly affected by increased vitamin A requirements. In 2002, the United Nations called for the global eradication of vitamin A deficiency and its consequences by 2010 (United Nations General Assembly 2002). The aim is to achieve this using a combination of promoting breastfeeding, improving diet by better use of available vegetables, enriching foodstuffs with vitamin A (biofortification), and the specific administration of supplements (e.g., together with vaccinations). Genetically modified plants could provide a contribution to this within the framework of a biofortification strategy.

PRODUCTION AND EFFICACY

Rice is the most important staple food for more than 3 billion people, most of them in Asia but also in some African countries. It forms beta-carotene (or provitamin A) naturally only in its leaves, but not in the rice kernels which are eaten. Since no rice varieties have yet been identified which could do this, the aim of the Golden Rice project - which has been going on for almost 20 years - was to use gene transfer to incorporate an additional biosynthesis pathway for provitamin A into the rice, so that the kernels are enriched. The Golden Rice project was designed and initiated mainly by the mo-

lecular biologists I. Potrykus and P. Beyer and the main industrial partner as the owner of central patents was the company Syngenta.

The basic proof of the technical feasibility of the approach was published in 2000. By transferring two daffodil genes and one bacterial gene, rice strains were developed that are yellow coloured due to carotinoid accumulation (Schaub et al. 2005; Ye et al. 2000). In open field trials, rice kernels were formed that contained up to 6 µg/g carotinoids, of these about 50% was beta-carotene (<http://www.goldenrice.org>). On the basis of these prototypes, the company Syngenta developed rice strains containing significantly higher amounts of carotinoids, namely rice kernels with up to 37 µg/g (Paine et al. 2005), by replacing the original daffodil gene with a corresponding maize gene (known as "Golden Rice 2"). For "Golden Rice 2", model calculations were conducted to calculate its possible contribution to satisfying the requirement for vitamin A (Paine et al. 2005). According to these, consuming normal quantities of "Golden Rice 2" could contribute significantly to providing the required amounts of vitamin A at least in children, if rice is the staple food and is supplemented by other foods which provide vitamin A. However, it must still be empirically investigated in consumption studies in the target group whether the underlying assumptions in the model calculations are actually correct. The crucial factor is namely not just the beta-carotene content of the rice kernels but rather its bioavailability and efficacy in vivo, and these in turn are influenced by numerous factors. First tests in the USA indicate efficient uptake of beta-carotene so that sufficient vitamin A provision could be achieved by eating normal amounts (Dreesmann 2007). The aim of further studies (e.g., in China) is to check to what extent the anticipated nutritional effects can be achieved under everyday conditions. Field trial cultivation has been initiated in the Philippines under the auspices of the International Rice Research Institute (IRRI, one of the IARCs; Transgen 2008a).

It has been reported that more than 70 questions regarding patents must be clarified by the developers to permit the desired technologies to be implemented or to enable dissemination later without the patent holders being owners and there thus being resulting licence claims (Dreesmann 2007). The result is a compromise (<http://www.goldenrice.org>): Syngenta, the main licence holder of the employed techniques, has by its own account invested several million US dollars in the project. It has agreed to accord licence-free usage in developing countries to small-scale farmers with an annual income not exceeding 10 000 US dollars (which is quite a high income in very many countries). If one assumes that the aim is to achieve the biggest possible effect through broad diffusion of "Golden Rice" (perhaps also in industrial countries), in the long run the investment might well pay off for Syngenta in financial terms too.

OPEN QUESTIONS AND EVALUATION CONTROVERSIES

There are still a number of open questions and evaluation controversies bound up with the "Golden Rice" project.

Significance and aptitude for reaching superordinated goals (eliminating malnutrition and its consequences): Critics repeatedly cast doubt on the basic sense of combating malnutrition with biofortification strategies, since this does not combat or solve the real underlying problem, namely poverty. As mentioned above, the WHO endorses a package of measures (one of which is biofortification); each one of these has specific advantages and disadvantages and a limited reach (TAB 2005, p. 92 ff.). The question of whether the "Golden Rice" strategy is really an effective and cost-effective measure as part of the biofortification approach can ultimately only be proven in practice and thus is closely bound up with the second level.

Questions regarding business and economic distribution of profits: In the case of "Golden Rice", the genetically engineered characteristic is not really intended to lead to any added economic value. The above-mentioned solution to the licensing question provided by Syngenta at the very least raises issues of practical realisation, since this kind of model is a true novelty. How can and should the limitation on "free" use of the "Golden Rice" trait to farmers with an annual income of 10 000 US dollars be monitored? What happens beyond this? In which countries is this limit valid? What is the rule for those who farm as a secondary occupation?

Questions of local adaptation, acceptance and dissemination of "Golden Rice" and of preserving the diversity of seed varieties: Evidence of the basic efficacy of Golden Rice is a necessary but by no means a sufficient prerequisite for actually using it to improve nutrient supply in the population of the target countries under everyday conditions (Zimmermann/Qaim 2004). To be able to achieve the necessary distribution, "Golden Rice" must be available on the regional supply markets in the target countries. It must thus be accepted and cultivated by the rice farmers. To achieve this, the ability to synthesize beta-carotene must be introduced into locally important rice strains using conventional breeding without being detrimental to their other cultivation or yield features (activities in this direction are underway). It must also be guaranteed that the altered organoleptic features (i.e., the yellow colour, possibly taste) of the rice do not lead to its rejection by consumers.

In addition to these questions of "benefits", which were at the centre of the debate in the past few years, there are – as always with transgenic seeds – of course risk and regulation issues. At the very latest when it comes to actually licensing Golden Rice as a food in the affected countries, an intensive debate will start on whether it is in any way harmful to health. Those opposed to the use of genetically modified plants fear particularly that Golden Rice will potentially open doors in Asia where up to now there has been no or little cultivation of transgenic food varieties. The developers, promoters and proponents complain in turn that - even in a project which they deem to be highly useful - the concerns and regulatory requirements brought up are inappropriate, excessive and predominantly motivated by opponents of genetic engineering., which have led to unnecessary and unjustifiable costs and delays (<http://www.goldenrice.org>).

Overall, Golden Rice appears to be an example of the targeted use of genetic plant engineering for a superordinated development goal (reduction in malnutrition and the health disorders resulting from it) and indeed with realistic chances of success as part of a more comprehensive overall strategy. At the same time, it demonstrates the enormous influence of intellectual property rights and their owners, the large seed and agrochemical companies that are orientated towards genetic engineering. The question arises of whether in development cooperation this kind of public-private partnership is indeed a forward-looking and practicable model (e.g., for the development of far more complex genetically modified plants such as "supersorghum" as mentioned above).

ACHIEVABLE EFFECTS (HIGHER YIELDS, HIGHER PRODUCTIVITY, LOWER VULNERABILITY, HIGHER INCOME)4.3

The socio-economic effects of cultivating transgenic varieties so far are highly controversial. Basically, the problem is with extrapolating results from small samples and single years onto larger regions, entire nations or indeed cultivation worldwide.

Herbicide-resistant and insect-resistant crops should positively affect yield security, and ideally be able to reduce costs and thus increase income. The latter is, however, strongly dependent on the purchase prices, which are ultimately determined for cash crops on the global market (which can negate all the positive up-front effects on yield and costs). With the new kinds of genetically modified plants (for the molecular farming of "functional food", plant-made industrials" or "plant-made pharmaceuticals"), new sources of income could be created. However, the cultivation of such genetically modified plants is probably mainly conceivable in the form of contract cultivation and presumably would not play much of a role for small-scale farmers in developing countries.

According to TAB's results (2008), the lack of sufficient data makes it impossible to deduce or formulate any aggregated, durable statements on the agricultural-economic effects on developing and emerging countries, either for the countries or for the kinds or varieties of plants. The frequently used example of Bt cotton growing in China (Brookes/Barfoot 2006) is based on data which come from just a few years and just a few hundred hectares (out of a total acreage of 5.5 million hectares), and these data demonstrate great fluctuations (Pray et al. 2002). For Brazil, there are no publications at all on cultivation results, just mere estimations or predictions (TAB 2008, p. 144 ff. and p. 236 ff.). It is uncontested that particularly in China and India, but also in the Philippines and South Africa, the transgenic varieties are predominantly grown by small- and medium-scale businesses. This observation, however, does not allow any conclusions to be drawn on the cultivation results or the size or distribution of profits.

Serious scientific studies point to the basic problem, namely that the actual or possible benefit and profit to be gained from using transgenic seeds is influenced in many ways

through regional and operational factors. This includes the cultivation technique used currently or previously, the pest intensity, the strongly fluctuating price of seeds, and competing varieties, to name but a few factors. With thorough consideration of the specific conditions and a comparison of the alternatives that exist in varieties and cultivation techniques, it is of course possible to calculate quantitatively the way in which the cultivation of a particular (transgenic) plant variety has developed in a particular period of time under specific conditions, and which economic (and ecological) implications have occurred here. However, the influence of individual factors, e.g., of the genetically engineered transfer of a trait on the individual effects and the overall yield will not be amenable to exact determination in most cases. In exceptional cases this may be possible, namely if the genetically engineered trait provides a completely new option which is used on a broad scale and exercises a particularly strong effect – such as where the ploughless tillage possible with herbicide-resistant soybean has permitted a second sowing and harvest in large parts of Argentina. But even where the herbicide-resistant characteristic is just another option for combatting weeds, the effects are much smaller and must be analyzed in the context of the general development of cultivation methods and agricultural techniques.

EFFECTS ON SMALL-SCALE FARMERS

5.

As the previous sections have shown, there is no solid basis in the data to exactly determine the effects so far of the use of genetically modified crops in industrial or developing countries. As a result, the uncertainty about future developments is so great that prospective assessments of the use of transgenic varieties by small-scale farmers are marked to a high degree by superordinated normative assumptions. The crucial factors here are the underlying development model, the assumptions and explanations of the causes of poverty and hunger, the ecological concepts and objectives as well as the choice of effect dimensions considered. It is usually overall a question of resolving the issue of whether or not the implementation of transgenic seeds ultimately has a positive effect on the development of the local, regional, national, or global communities/societies. It is evident that values and positions have an enormous influence here on the result, and nobody can seriously expect or require an "objective scientific" answer. The dependence on values and interests and the level of complexity make it not surprising that the stakeholders involved come up with entirely disparate overall assessments.

Put in simple terms, there are two opposing perspectives which form the *poles* of the overall judgments: the *(global) market perspective* and the *regional ecological perspective*.

CHANCES

In line with the (global) market perspective, genetically modified crops represent an innovative production resource which should indeed aid even small-scale farmers in developing and emerging countries to produce more efficiently, i.e., with savings in costs and work, as well as with a secure yield. A stronger patent protection and assured license or technology fees are necessary prerequisites for the development and supply of transgenic varieties in order to be able to refinance the development costs. In comparison to conventional cultivation, e.g., of soybeans, maize, and cotton as cash crops, ecological (and health) advantages are assumed primarily through the use of herbicides that are better tolerated by humans and the environment, ploughless soil tillage and the savings in insecticides. The challenges of future agricultural production are seen overwhelmingly in increased yield due to the population growth and in the most recent past also in a stronger demand for "energy crops" to reduce CO₂. For the near future, new combinations of the existing traits of herbicide and insecticide resistance and their transfer to all possible further plant species (aubergine, sorghum, sugar cane, to name but a few) form the main perspective of green biotech, and - in the medium term - tolerance to drought and heat as well as possibly content modifications should be added. This could lead to cultivation being designed in a more resource-saving way, and even being retained with progressive climate change and extended to regions that were previously unused. In addition, dietary deficits could be compensated for by the enrichment of individual plants ("Golden Rice", for Africa "Supersorghum"; see Sect. 4).

RISKS

By contrast, according to the regional ecological perspective, genetically modified crops (or genetic engineering in general) represent a basically unadapted technology which destroys the traditional local methods of cultivation, some of which have been handed down by the indigenous population. Because the latter are orientated towards diversity (of the species and varieties cultivated), free exchange and - with this - continual improvement of the seeds and production to supply their own needs as well as local markets and at the most regional or national markets, they are regarded as particularly socially and environmentally compatible. For the frequently practised multiple and mixed cropping, a high pest level, which Bt plants aim to control, is irrelevant, as are chemical weed control or sparing tillage. The solution to abiotic location problems (drought, heat, salinity) is seen in the choice or even conventional breeding of adapted species and varieties. Malnutrition should not be solved by a technological approach, but by anti-poverty measures and empowerment. It is not high-performance seeds, but stepwise, intelligent integration of modern agricultural technology which seems sensible and adaptable. The only sustainable perspective for global agriculture in these terms would be detailed, decentral and ecological (in the sense of cultivation).

CONCLUSION

From the neutral perspective of an institution of technology assessment, we must infer that an evaluation of the future potential of genetically modified crops for small-scale farmers is not seriously possible with the current status of knowledge. Existing restrictions of the available transgenic varieties have been a topic at various points (cf. Sect. 1.8 and Sect. 3), and possible opportunities are seen by almost all experts, above all in the use of varieties that will be developed in the future to particularly benefit agriculture in developing countries. Their development and evaluation thus remains a task for the future (see Sect. 7.2).

SUMMARY OF RESULTS

6.

Even after 20 years of research and 12 years of cultivation, there are as yet no transgenic varieties that are specific to developing countries. It is controversial whether the reasons for this lie primarily in the technology itself, in the interests of the technology owners, or was caused by (overly) strict licensing conditions. There are, however, adapted HR and Bt varieties, mainly as a result of hybridization into regional varieties.

Although there were and still are a large number and variety of research and development projects overall on transgenic plants for the particular benefit of agriculture in developing countries – in the countries in question, in international agricultural research centres, and in some cases in cooperation with institutions in industrial countries –, these seem as ever to be mainly at early stages. It is widely assumed that worldwide up to now comparatively few resources have been used, from which it is inferred that the actual potential of transgenic plants has not yet been properly determined for developing countries. Proponents of a stronger use of genetically modified crops additionally emphasize that regulatory and administrative licensing and cultivation conditions in connection with continually inadequate capacities in science administration have prevented further successes in development. It is indisputable that, regardless of type and implementation, specific regulation of transgenic plants makes its research and development more expensive than that of non-transgenic, conventional plants or varieties, and this is an obstacle in any case.

GROWING GENETICALLY MODIFIED CROPS

In 2007, the estimated global acreage of genetically modified crops was around 114 million hectares (representing approx. 5% of arable land worldwide). Genetically modified crops were grown in 23 countries (James 2007). Twelve years after the commercial introduction of transgenic plants, more than 99 % of the acreage still displays only two genetic traits (herbicide tolerance and/or insect resistance) and consists of four crops: soybean (51%), maize (31%), cotton (13%) and rapeseed/canola (5%). The global acreage of genetically modified crops has grown continually, in some im-

portant emerging countries as well. A total of 88% of genetically modified crop acreage is located in the countries of North and South America.

Commercial cultivation has taken place up to now almost exclusively in the so-called emerging countries and is quite predominantly restricted to two cash crops: HR soybean in South America (Argentina, Brazil, Paraguay, and Uruguay) and Bt cotton in India and China. In addition there are HR and/or Bt corn acreages, above all in South Africa, Argentina and in the Philippines. Taken as a whole, the role of this cultivation is hardly ever for the purpose of ensuring food security or for local markets. However, in India and China Bt cotton is grown almost exclusively by an estimated 11 million small-scale farmers.

In some cases, these plant products which are processed and exported for fodder and textile manufacture are of great economic significance. Cotton, for instance, is China's most important agricultural product overall in terms of value, and about 70% of it is obtained from transgenic varieties/breeds. In Brazil, soybean is the central agricultural product, with about a 10% share of the entire export of the country, and in 2007 about two-thirds of it was produced with the aid of transgenic varieties.

BREEDING AIMS AND GENETIC ENGINEERING APPROACHES

The *crop yield*, both of individual parts and of the plant as a whole, is determined multifactorially as a complex feature and up to now genetic engineering has only been able to exert a minor influence on it. Improving the plants' resistance to influences that *reduce* the crop yield or quality such as diseases and pests or lack of nutrients and water, i.e., the creation of resistance or tolerance in order to *secure crop yield* can be partly procured through individual features or just a few characteristics and is thus in principle more accessible to genetic engineering. In addition to the varieties grown up to now that are resistant to insects and herbicides, there has been intensive research for many years above all into variants that are resistant to viruses and fungi. Up to now, a number of virus-resistant varieties have been licensed and grown on limited acreages, including peppers and tomatoes in China, and pumpkin and papaya in the USA. Similarly, resistance or tolerance to cold, drought, or salinity that can be used by genetic engineering has also long been the subject of research, and in the current debate has moved more into the limelight, without any concrete results being foreseeable here.

In the area of the *quality characteristics* of plants, genetically engineered modifications with the aim of obtaining new, industrially practicable substances such as »plant-made industrials« or »plant-made pharmaceuticals« is a central feature of many R&D projects, but so far any concrete use has been of little significance. In this regard, there are hardly any perceptible aspects specific to developing countries, with the exception of the biofortification approach, i.e., the (genetically engineered) enrichment of basic foodstuffs with vitamins or essential minerals. Relevant projects are being pursued for the target group of poor populations in Africa and Asia and have been promoted for some time on a larger scale by the Bill and Melinda Gates Foundation; the example of

"golden rice" which has achieved particularly good progress is discussed in depth in the report.

THE POTENTIAL CONTRIBUTION OF GENETICALLY MODIFIED CROPS TO A SUSTAINABLE DEVELOPMENT OF DEVELOPING COUNTRIES

Considerable economic power and comprehensive research capacities are necessary to make a successful national, proprietary development of transgenic varieties realistic – worldwide this has only been achieved in China in the stricter sense. In some countries, R&D on and with genetically modified crops are strongly dominated by international companies (e.g., Brazil and probably India too), or the extent of the activities and capacities is (very) limited. Important barriers and hurdles are the patenting of many procedures and products as well as unclarified regulation in some cases, which makes the prospects for the success of an R&D commitment hard to calculate.

Particularly in small or poor countries, the available capacities in terms of science and infrastructure are insufficient for autonomous agricultural research in general and for genetic engineering development in particular. In these countries it must thus be clarified what kind of cooperation (with private companies, international institutions/organizations, public R&D in industrial countries) is particularly promising and desirable in the search for the best possible solutions for country-specific problems. The participation of smallholder representatives and other social groups has so far been mostly low or hardly developed in the formulation of research requirements and the search for new (technological) agricultural strategies. Basically, most countries lack a clear and practicable concept for setting in motion a scientific, social and political agreement regarding the aims, strategies and paths to be followed for sustainable agriculture – this is indeed also true for the industrial countries.

ECONOMIC RESULTS SO FAR: POOR DATA

Due to insufficient data, it is currently impossible to carry out a final evaluation of the size and distribution of profits in terms of business and economics which have been achieved by cultivating transgenic plants in developing and emerging countries. Studies which claim to be able to do this are not backed up scientifically and are based on unstable projections. The studies published to date on the economic results of Bt cotton cultivation in China are, for instance, based on the data from just a few years and just a few hundred hectares (out of an overall acreage of 5.5 million hectares) and demonstrate enormous fluctuations; for Brazil, no publications at all exist on the cultivation results, only estimations. It is undisputed that, particularly in China and India but also in the Philippines and in South Africa, transgenic varieties are predominantly grown by small- and medium-scale businesses. This observation, however, does not permit any

conclusions to be drawn with regard to cultivation results or to the size or distribution of profits.

Serious scientific overview studies point out the basic problem that the actual or possible benefit and profit from the use of transgenic seeds is influenced in many ways by regional and operation-specific factors, including the existing or previously used cultivation technique, pest intensity, the strongly fluctuating price of seed, the competitive varieties and many other factors. Of course, by observing individual cases and taking the specific conditions into comprehensive consideration, and by comparing the alternatives in varieties and cultivation techniques, it is possible to quantitatively determine how the cultivation of a specific (transgenic) plant variety has developed under certain conditions within a defined time period and which economic (and ecological) implications arise here. The influence of individual factors, e.g., the characteristic transferred by genetic engineering, on the individual effects and the overall yield will, however, not allow an exact determination in most cases.

FURTHER SOCIO-ECONOMIC ASPECTS

Further socio-economic effects of a widespread use of transgenic varieties can be observed at two levels: in the seed market (including the design of protection systems for intellectual property) and in the circumstances of agricultural structure such as the size of operations and ownership structure. In view of the position of power – to some extent a kind of monopoly – held by the large biotech seed companies in the field of transgenic varieties, which in part comes up against poorly developed, decentralized seed markets, pressing questions arise regarding the options for guiding further development.

Critics of the spread of HR soybean in Brazil, for instance, assume that any possible economic advantage does not benefit the agricultural family businesses and traditional producer communities. These, they say, are increasingly exposed to the danger of marginalization as the orientation of Brazilian agriculture becomes increasingly strong towards global markets, and this is further fired by the spread of HR soybean. The beneficiaries in agriculture, they maintain, are large farms and cooperatives, and the clear losers are vendors of produce explicitly free of genetic engineering, including the organic farmers whose market is jeopardized by the risk of contamination from transgenic soybean. In addition to this, the dominance of Monsanto's HR soybean can be seen to exert a bad influence on the number of small and medium-sized seed producers in Brazilian soybean cultivation and their range of varieties.

ECOLOGICAL AND HEALTH RISKS

An evaluation of the possible risks and negative effects actually observed in the use of transgenic varieties depends decisively on the standard chosen for comparison and the levels of impact observed. A crucial role is played here by the status quo of agricultural practice, and the agricultural principle followed in each case.

In considering which risk aspects, planes of impact, and chains of effect are particularly relevant for or indeed specific to developing and emerging countries, two dimensions can be distinguished: The type and size of the risks are marked strongly by the conditions of geography and natural space, their controllability by "development-related" and institutional parameters. With regard to the parameters of *geography and natural space*, questions regarding biological diversity come up more strongly in some developing and emerging countries than they do in European countries, for example, especially when they house so-called centres of biological diversity that are regarded as particularly important and worthy of protection or other regions that are the source of agricultural crop plants.

With regard to the *development-related* parameters, one important topic consists of questions pertaining to their regulation or establishment and realization; here it is virtually regarded as a consensus in the debate that in many or most developing and emerging countries there continues to be great deficiency in terms of institutions and capacities. On the part of the users, the effects of using high-performance transgenic seeds can be influenced particularly by the level of education and knowledge as well as by the amount of capital in the businesses. It is crucial for the possible effects on environment and health that Good Agricultural Practice is observed, e.g., in using pesticides. New varieties can also lead to changes in land usage over a wide area and thus have effects on the ecology. The dominant topic here in the risk debate on the implementation of transgenic varieties in developing and emerging countries are, however, the related socio-economic and to some extent also socio-cultural questions, e.g., with regard to the effects on traditional crop-growing methods and seed markets.

RISK EVALUATION AND REGULATION

In considering Bt varieties as a possible option for plant protection – but not as an option which can be used indefinitely for dealing with the pest problem –, which must be seriously weighed against other options, many of the particular risks expressed in the debate are put into perspective (effect on non-target organisms, other ecotoxicity, resistance problems). At the same time, it must be required that the standard used to compare Bt varieties should not just be conventional practice but that other innovative, knowledge-based options, e.g., from the field of integrated plant protection and organic farming should also taken into consideration.

A risk evaluation of HR varieties seems even more complex since their implementation causes many and indirect kinds of effect on the cultivation technique (reduction in tillage, fuel savings) and on land usage (crop rotations, increasing acreage). These would have to be considered in the framework of a comprehensive risk assessment and evaluation in addition to the direct effects of the herbicides used and saved on humans and the environment and be weighed up against these. To carry out an evaluation on a regional or national level, it would then be necessary to have a weighting, which legally protected goods (e.g., health, soil fertility, biological diversity, CO₂ emissions,

rural development, resource distribution) have priority (which in turn can only be inferred from the developmental aims of a region or a country) and what contribution can be provided here by genetically modified varieties compared with alternative options.

Basically it must be assumed that the overuse of an option, i.e., here the concentration on one single or just a few crops in terms of acreage and crop rotation contravenes the principles of Good Agricultural Practice and in the long run means great problems.

In the area of risk regulation, regulation strategies and policies are still considered to be inadequate or completely lacking in many countries. Even developed legislation is of little use, however, if the political and economic balance of power stand in direct opposition to an application. And where the social debate on the use of transgenic seeds is conducted very intensely, there is often only poor development of comprehensive risk communication on the part of the authorities.

AREAS OF ACTION

7.

In terms of perspective, two tasks are particularly significant in dealing with the implementation of transgenic seeds in the framework of developmental cooperation: the (continuing) task of expediting capacities and basic conditions in the field of biosafety and regulation as well as answering the central question of how to better elicit and employ a possible future potential for transgenic cultivation methods than has been the case for developing and emerging countries.

CAPACITY BUILDING FOR BIOSAFETY AND REGULATION 7.1

The fact that according to "strict" European standards the necessary scientific and political/regulatory preconditions still do not exist in most developing countries or even in any comprehensive form in highly developed emerging countries justifies a strong emphasis in developmental cooperation on "capacity building" in the field of biosafety in terms of the Cartagena Protocol or with a view to putting it into practice. Support of this kind seems useful and necessary given that genetically modified plants are being grown on an increasingly large scale and are continuously advancing, in some cases through uncontrolled channels into more and more countries. Three aspects of the topic biosafety and regulation are (or remain) probably particularly important for the future in developing countries, and are thus remits for intensive cooperation:

- > *Improvement of Risk Evaluation and Risk Communication:* With regard to the import and cultivation of transgenic seeds which have been developed, assessed as safe, and first licensed in a different country, the further development of criteria and procedures for decision making would be helpful: which elements from previously

conducted safety assessments could be reused and which should be newly investigated specific to the country or region. Here, it seems useful and necessary to include particularly affected social groups. In addition, there must be comprehensive and careful risk communication.

- > *Increasing Knowledge of the Threat to Biodiversity Through the Use of Transgenic Varieties:* Although biodiversity is the superordinated legally protected ecological good, knowledge of it is only rudimentary in many ways. The influence on the diversity of the country's varieties (and other agrobiodiversity) as a result of changed cultivation techniques and by developments in the seed markets and possible consequences of the cultivation of genetically modified plants in the centres of diversity (via the outcrossing of transgenic characteristics into related wild varieties or types) still constitute important topics for investigation in which the use of farmers' knowledge should be accorded a position of prominence.
- > *Establishing Functioning Systems of Coexistence, Proof of Origin, and Labelling:* Independent of the use of transgenic varieties, identity preservation (IP) is regarded as a central requirement and challenge for food production as the latter becomes increasingly internationalized and industrialized, and which as supermarketization progresses is becoming an even stronger factor, directly in the urban centres of developing countries. European countries can offer comprehensive know-how in procedures for labelling and for proof of origin and in addition have a responsibility as importing and exporting countries. Since global agreement on compulsory standards as set out in the Cartagena Protocol seem to be destined to remain difficult for the foreseeable future, bilateral and voluntary systems and agreements represent an important option.

Going beyond these concrete tasks in the field of biosafety and regulation, it would be an important future task for many countries to achieve a better foundation and framework for risk assessment through basic agreement on the aims, strategies and paths to sustainable agriculture.

ASSESSING THE AGRICULTURAL POTENTIAL OF GM PLANTS 7.2

Evidence suggests that for the evaluation of the future problem-solving potential of genetic breeding approaches it is *not sufficient to consider existing developments*, since the commercially available transgenic plant varieties as well at least as those at an advanced stage of development only represent a limited section. The study of genetic breeding approaches may be conducted in a decentralized way, even in publicly financed institutions and smaller companies, but the real development of genetically modified plants, by contrast, is conducted predominantly by a few large seed companies. Many of the most significant of these, first and foremost Monsanto, but also Dupont/Pioneer, Syngenta, Bayer CropScience and BASF, are also producers of important agricultural chemicals. In connection with the (literally) exclusive significance of

patent-protected procedures in the genetic engineering of plants, it is thus glaringly obvious that the genetically modified plants available on the market represent those that fit best in the portfolio of these companies and *by no means all those which could potentially be successful on the seed markets*. If the development to date continues, it is to be expected that these few large biotech seed companies will continue to dominate to the same extent if not more, since they of course have a primary interest in successful and profitable varieties whose transgenic features fulfil their function for as long as possible for as many users as possible. Diversification under the conditions of the world agricultural market is subject to relatively narrow economic limits so that it cannot realistically be expected that these companies will of their own accord develop a variety specifically designed, for instance, for poor developing countries or regions.

Overall, even 25 years after the development of the first transgenic plant and after 12 years of widespread use of transgenic seeds, there is still great uncertainty:

- > Does genetic engineering harbour dormant potential for sustainable agriculture in both industrial and developing countries?
- > Is it even possible to elicit this potential, particularly when one considers the basic economic and legal conditions?
- > Are there other options which are more promising in terms of ecological and social success and which are thus to be preferred?

There are many arguments in favour of steering towards a solution-orientated approach in search for potential future agricultural technologies and cultivation methods. With a view to transgenic plants, this means examining genetic engineering options without a predetermined result. Thus, with reference to the challenges of climate change and problems of water supply or other stress factors, it would be appropriate to first inquire into the existing and foreseeable agricultural challenges overall and only then into the means of possibly or necessarily adjusting cultivation methods. The contribution of plant breeding will be encountered here in some parts of the question, and only then can options for green genetic engineering be examined in a sensible way. The same is true for the problem of micronutrient deficits (cf. the example of Golden Rice in Sect. 4.2) and many other examples. Of course, this does not absolve us from the obligation to consider dimensions specific to the technology (e.g., the increased requirements on measures to guarantee biosafety) – this must form a part of the consideration process.

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