# Biodiversity: The Impact of Biotechnology

By

**Richard Braun**
BIOLINK
Worb, Switzerland

and

**Klaus Ammann**
Botanical Garden, University of Bern
Bern, Switzerland

**Glossary and Abbreviations:**

**Biodiversity** - The multitude of different living beings in a particular ecosystem or on the whole earth

**Biotechnology** - Use of cells (plant, animal, microbial) and their components to produce useful substances and other products

**Genetic Modification (GM)** - introduction of isolated genes or pieces of DNA into another organism. Synonymous terms are gene technology, genetic engineering

**GMO** - genetically modified organism. A synonymous term is transgenic organism

**GT-Food** – food produced from GMOs

**Modern Biotechnology** - biotechnology including the use of genetic modification of the producer cells and other newer procedures

**Transgenic** - genetically modified

## 1. Introduction

The Convention on Biological Diversity requires that all Member States take measures to preserve both native and agricultural biodiversity. The intrinsic value of species and ecosystems, in addition to their value as starting material for finding new products, is the basis for these measures.

The biggest threat to biodiversity is habitat destruction. The ever increasing spread of cities and the accompanying expansion of agriculture must be held largely responsible. Humid tropical forests are particularly valuable reservoirs of biodiversity and are currently being seriously threatened. As the human population expands, the need for food is expected to double in the next 30 years with the ensuing threat of massive habitat destruction particularly in the less developed countries. Increasing crop productivity on the land already under cultivation would prevent or at least reduce habitat destruction. One of several measures aimed at increasing yields is the use of better seeds, including those enhanced by modern biotechnology. Many other measures in the technical, socio-economic and political fields need to be taken at the same time in order to balance intensification and sustainability of modern agriculture.

Modern biotechnology offers new means of improving rather than threatening biodiversity. If properly tested for both risks and benefits to humans and the environment, transgenic crops are more likely to increase agricultural biodiversity and help maintain native biodiversity rather than to endanger it. Such applications need to be judged by the criteria of improved sustainability and compared to current as well as alternative farming practices.

## 2. The Essence of Biodiversity

Biodiversity is the multitude of different living beings in a particular ecosystem or on the whole earth. Biodiversity can be seen and studied at different organisational levels: genetic, organismal and ecological. It touches both upon native environments on land and sea as well as agricultural and other man made surroundings.

### 2.1 Native biodiversity

The biodiversity we observe today is the result of 3.5 billion years of evolution. Through the processes of mutation and selection all living organisms we know today, as well as those that ever lived before, developed from one single-cell micro-organism. How this first living being arose 3.5 billion years ago is still a matter for speculation. This unitary origin explains why all organisms share the same basic chemistry: DNA is always the storage molecule of genetic information and the complex process of protein biosynthesis is virtually the same in all organisms. Metabolic pathways too, are similar in all organisms, e.g. the reactions by which energy is generated or the way fatty acids, sugars and amino acids are made. Separate species arose, when mutations between relatives no longer allowed for interbreeding, for instance after geographic or reproductive separation.

Dinosaurs are by no means the only creatures of the past that became extinct: far more organisms lived at some time on our earth than are living here today. The vast majority, probably more than 99%, of species that arose on this globe, disappeared again. This shows that evolution is an ongoing process, with species coming and going. This dynamic situation is important when discussing the conservation of species living here today. In the long term view, there has never been any stability with life on earth - only change. However, these changes were very slow compared to the length of a human life, or even compared to the time humans have existed. Clearly, today, with the massive amount of human interference on the globe, changes are much faster than at any other time in the last 65 million years, the point at which the trilobites and later the dinosaurs and many other creatures vanished from the surface of the globe in a relatively short time period.

As suggested by Raven, the number of species of plants, animals and eukaryotic micro-organisms is probably around 10 million today, but only 1.4 million have been characterised and given a name by scientists. There is a large variation in what is known about the different groups. Virtually all of the 40'000 vertebrate animals are known and most of the 300'000 vascular plant species as well. On the other hand, there are likely to be over a million species each of fungi and nematodes, of which only 70'000 and 13'000 have been named. There are thought to be far more than a million different insect species as well. With prokaryotes the situation is even more extreme: about 5000 bacteria and viruses have been named individually, yet the total number in both of these two groups may well according to Bull be in excess of one million. Since many micro-organisms and viruses are associated with specific plants and animals, Staley considers their own biodiversity will depend on the biodiversity of their hosts, as well as the micro-organisms' own host range.

All the different species of plants and animals are not living an independent existence, but are associated in specific communities and ecosystems to form more or less stable associations. One such association is, for instance, the humid (and dry) tropical forest which is generally thought to have the highest degree of biodiversity, with more tree species per km2 than there are tree species in North America or in Europe, as discussed by Burslem. Another example are specific types of alpine meadows or specific sorts of rivers or ponds. Biodiversity needs not only to be considered in qualitative terms of the species present, but also in quantitative terms considering how many individuals of certain species of plants and animals are present. With large mammals this is quite easy to determine, but impossible with micro-organisms. Often the number of species found in a given ecosystem is taken as a measure of the biodiversity of that system: other criteria are more difficult to apply.

In this paper we will concentrate on terrestrial biodiversity, although it is clear that streams, lakes and oceans are the habitats of a vast biodiversity of animals, plants and micro-organisms. In addition, as calculated by Naylor, they are an important source of protein as food for humans and feed for farm animals, with about 120 millions tons of catches per year.

## 2.2 Agricultural biodiversity

In addition to biodiversity in the wild, there is the biodiversity of organisms used for farming and other human activities. In agriculture, 7000 species of plants are used by farmers somewhere in the world, but only 30 species provide 90% of our caloric intake as observed by Haywood. Within these preponderant crop species there are many hundred thousand varieties (landraces, cultivars) adapted to local climates, farming practices, cultural predilections like taste, colour, structure, ability to store the products etc.. Much of this large crop diversity is important for providing starting material for breeding. However, it must be recalled that the genetic diversity found in crops is much less broad than the genetic diversity observed in plants or animals living in the wild, which points to the importance of wild species for agricultural breeding programs. The top three crops are wheat, rice and maize (corn) with around 500 million tons annual production each. Traditional breeding brought us in the trap of narrowing down the genomes, and wisely used biotechnology could bring back at least that part of genetic diversity which enhances pest resistance and perhaps yield.

There are many indications that mixtures of varieties of a crop or of different crops may give higher yields and be more resistant to pests and diseases than monocultures, as reported recently by Zhu for rice in China However, even in mixed cultures high quality, well defined varieties and pure seeds are required and the sustainability of mixed cropping related to pest management has still to be proven. In addition, it is still not clear, whether in natural, non-agricultural habitats yield is basically dependent on biodiversity. On the basis of the same experiments, some researchers claim that loss of species leads to a reduction in biomass, while others disagree, as demonstrated by Hector and by Kaiser. There may not be generally valid correlations between biodiversity and biomass yield, neither in agricultural nor non-agricultural settings.

## 2.3 Human population expansion

The one species that is still globally expanding in numbers are humans. The world population has gone up from 2.5 billions in 1950 to 6 billion today; it is expected by the UN to reach 8 billion in 2015 and 9 – 10 billion in 2050. Over 95% of the expected population increase will be in the less developed countries (LDCs). In those countries, most of the population growth will occur in the cities. The additional population will require more space to live in, more water, more energy, more food and more services. For the years 1995 – 2020 the largest relative population increase (80%) is expected in sub-Saharan Africa: in absolute numbers it is expected to go from 500 to 900 million. Whether the HIV/AIDS epidemic with an estimated 25 million infected in this region today, will in the next 25 years substantially affect population dynamics, is not clear. Most of the infected are of reproductive age, as pointed out by Cohen. In the context of this paper it is important to realise that the FAO estimates that there are globally over 800 million people who don't have enough to eat today and it is imperative that more food be produced for them.

**3. International agreements**

In view of the importance of biodiversity for the future of mankind, several international agreements have been reached. Since this has only occurred in the last few years, the long term impact of these agreements can not yet be estimated.

3.1 The Convention on Biological Diversity (CBD)

Recognising that biodiversity of organisms in the wild should be maintained both for their own intrinsic value, but also on practical grounds, the United Nations prepared this Convention and succeeded in having it adopted in 1992. It entered into force in 1993. This is the first time that a large majority of States, though not the USA, have agreed to a legally binding instrument for biodiversity conservation and the sustainable use of biological resources. A radical change brought about by the CBD is the recognition that States have a sovereign right over biodiversity within their own territory, while previously organisms were considered the common heritage of mankind. Living organisms or their products may, under the terms of the CBD, only be removed from a country under mutually agreed conditions. The CBD is a comprehensive approach to biodiversity conservation of both wild and domesticated species. It aims at conservation at the genetic, species and ecosystem levels. As reviewed by Buhenne-Guilmin action is delegated to the national level obliging States to assess biodiversity, enact legislation for its conservation in situ and ex situ, and to enforce legislation within national boundaries.

The field of biotechnology is particularly touched by articles 16 and 19 of the CBD, since they require a fair and equitable sharing of benefits derived from the use of genetic resources. This includes providing facilities and financial means for technology transfer and open access to scientific and technical information. The sovereignty over biological resources means that no-one can remove specimens of plants, animals or micro-organisms from a country without the prior consent of that country. One example of a joint effort in "bioprospecting" is a search for specific active ingredients of plants by the Merck Company in the tropical forests of Costa Rica. This brought the country 2 million dollars over a five year period, as well as the potential of royalties, if profitable products emerge, as reported by Manteo. A small number of similar agreements have been concluded elsewhere in the world.

The regulations of the CBD have only been in operation for a few years. It is too early to assess their long term effects. As far as biotechnology and "bioprospecting" is concerned, it will take more time to establish smooth administrative procedures to allow simple routine implementation of close collaborations. Only if national authorities from countries rich in biodiversity as well as pharmaceutical or other companies see the mutual advantages to be gained from such collaboration, will this system spread. One of the real obstacles are the exorbitantly high costs of drug testing needed to be done to meet strict and justified regulation before marketing. The expectations of some LDCs to make rapid earnings may have been too optimistic. The search for natural, highly active pharmaceuticals in wild plants may often be more cumbersome than laboratory searches using genomics, rational drug design and combinatorial chemistry.

3.2 The Cartagena Protocol on Biosafety

The CBD provided a basis for developing and formulating a further international agreement, namely one regulating primarily the trans-boundary movement of living GMOs. After much debate in 1999, the new protocol was agreed on in early 2000 under the name of the "Cartagena Protocol on Biosafety". The "Intergovernmental Committee for the Cartagena Protocol on Biosafety" had its first meeting in Montpellier in December 2000. It paved the way for launching a pilot phase of the "Biosafety Clearing House", a centre for information exchange as explained on the web.

The Protocol is a world-wide regulation for the transfer, handling and use of GMOs that may have an adverse effect on biodiversity, also taking into account risks to human health and focusing on transboundary movements. It makes explicit reference to the precautionary approach. It establishes an Advance Informed Agreement (AIA) procedure for imports of GMOs intended for introduction into the environment and an alternative procedure for mass movements of GMOs intended for food, feed and for processing (commodities). The permit for transboundary movement will or will not be issued on the basis of a risk assessment procedure by the national competent authority. The Protocol does not pertain to pharmaceuticals or other non-living products made by genetic modification.

In practice, the Protocol will be most important for the import of transgenic seeds. It requires a risk assessment by the national authorities and allows countries to reject GMOs. The protocol specifies that "lack of scientific certainty due to insufficient scientific information and knowledge regarding the extent of the potential adverse effects …. shall not prevent the party from taking a decision:" This may or may not be in agreement with the WTO rules, but will need to be tested in the courts. If there are disputes between the interpretation of the Protocol and the WTO regulations, which allow for trade barriers virtually only if there are scientific reasons to do so, the outcome of such disputes will depend to a considerable degree on the quality of scientific data assessing benefits and risks of GMOs.

The Protocol is likely to become operational in the year 2002, after ratification by 50 nations. Early in 2001 it had been signed by 86 nations and ratified by two. The Protocol will, as pointed out by Mahoney, be a challenge to the scientific community to provide solid scientific data to convince national authorities of the benefits of transgenic crops and their relatively low and manageable risks. It is far too early to make any assessment of the Protocol's effect. Hopefully it will allow (and not prevent) planting GM crops that may have real advantages for LDCs, while at the same time minimising their risks to humans and their environment. The Protocol may possibly contribute to a better public understanding of what transgenic crops are, but it may on the other hand, by treating

GMO crops as a special group, increase fears of a negative impact, even in the absence of any science-based data showing such an impact. It will be difficult to move forward with the Precautionary Approach, if it is taken as a stringent principle. It will be more advisable to see the Precautionary Approach as guiding a case by case decision making tree, in the sense of a systems approach as described by Verma Niraj of the Churchman School from Berkeley, California.

## 4. Loss of biodiversity and conservation

Losses of biodiversity are undoubtedly occurring in many parts of the globe, often at a rapid pace. These losses require countermeasures such as an increased effort towards conservation by many different means.

### 4.1 Reduction of biodiversity

The loss of biodiversity can be measured by a loss of individual species, groups of species or decreases in numbers of individual organisms. In a given location the loss will often reflect a degradation or a destruction of a whole ecosystem. Recently the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) of the CBD ranked the priority of threats to global biodiversity in the following manner: first comes habitat loss (most of it through the expansion of cultivated land), second comes the introduction of exotic species. Habitat loss comes not only from taking more land under the plough, but also from expanding cities and road building. In addition, habitats can be damaged by flooding, lack of water, climate changes, salination etc., all phenomena which may be both natural or man-made.

Since tropical humid forests are particularly rich in biodiversity, their destruction is disproportionately damaging to biodiversity. It is estimated by Pimm and Raven that of the original 16 million km2 of these forests known a century ago, only half are left, with about one million km2 being destroyed every 5 to 10 years. Burning and selective logging may damage an even greater area. Biodiversity is not homogeneously distributed over the humid tropical forests, rather there are hotspots with a particularly high level of biodiversity. The hotspots are according to Myers of particular interest for the implementation of conservation measures.

The second most important reason for loss of biodiversity is invasion by exotic plants and animals. Knowingly, or unknowingly, imported plant species threaten the native ones by being highly competitive and often by lacking local predators, such as insects or birds. One of the most extreme examples is seen in the pampas of Argentine, a flat grassland with a moderate climate, from which nearly all the native grasses have disappeared and have been replaced by European plants. This invasion was brought about by European farmers, bringing animals and crops, as well as accidentally spreading many different weeds. This phenomenon was already noted in 1833 by Charles Darwin, as recorded by Crosby. Still today, droves of gardeners transport seeds all over the globe and never think of the possible threat to biodiversity, as suggested by Ammann. It is estimated by Sukopp that one in ten imported plants may spread in a modest way and that one in a hundred may turn into a nuisance weed. Even in today's Europe invasion by exotics may threaten ecosystems. In the Ticino region of Southern Switzerland Robinia pseudoacacia, a native of North America, is displacing chestnut and oak trees, whilst in the Northern regions of the country Solidago canadensis is replacing native Irises in swampy areas. Islands are particularly threatened by invaders, as is well documented for Hawaii, New Zealand or the Galapagos Islands. For North America it has been estimated that damage caused by exotics amount to137 billion dollars a year, as calculated by Pimentel. Although such calculations are in detail fraught with uncertainties, there is no doubt that the costs of exotics are tremendous.

Exotic biological control agents are often introduced into agricultural ecosystems on purpose, in order to control pests or weeds without resorting to chemical controls agents. Whilst there are some success stories, Strong pointed out that such systems may also go wrong. One example is the introduction of the seven-spot ladybird which was intended to fight the Russian wheat aphid. The consequence, however, was the disappearance of the native ladybirds, for which the seven-spot import was a competitor and an actual predator. Another example is the decimation of the large American moths, which are killed by European Compsilura flies, introduced nearly a century ago to control the gypsy moth. Field experiments recently done by Jensen showed that caterpillars of the American moth Cecropia were killed by massive infestations with Compsilura maggots.

Whether transgenic plants are specifically prone to spread in the long term, cannot be said today on the basis of experimental evidence. However, one would not expect this to be the case unless the transgenic plant had an increased fitness. There is no good argument why crops that have for centuries depended for survival on human care should become weeds just because of the addition of one or a few well characterised genes, in addition to the many thousands of genes they already carry. However, this issue needs to be studied carefully in a case by case manner, keeping in mind that the absence of a negative effect can never be proven with absolute certainty under all circumstances. The results of a fairly long-term study of the performance of transgenic crops in natural habitats were recently presented by Crawley. Four different crops (oilseed rape, potato, maize and sugar beet) were grown in 12 different habitats and monitored over a period of 10 years. In no case were transgenic plants found to be more invasive or more persistent than their conventional counterparts, in agreement with the general hypothesis put forward above.

### 4.2 Conservation Strategies

Conservation may be in situ or ex situ, either in the natural or semi-natural habitat, or in some purpose-built environment. The choice of one or the other technique, or a combination of both, will depend on the particular case. In situ conservation will involve the maintenance and protection of natural habitats, while botanical gardens and seed banks are used for the ex situ conservation. Both of the latter require precise knowledge of taxonomy.

Conserving a substantial, but selected fraction of the humid tropical forests would still allow half or so of their indigenous species to be preserved. This would require a selection of the most appropriate areas, called the hot spots. Protecting huge tracts of land will pose major socio-economic and political problems. How forests destined to be protected from human encroachment can be kept free of hungry people in search of potential farmland was asked by Mace. Jennings thinks that a viable strategy may be to find a sustainable livelihood for rural populations in connection with conserving tropical humid forests. Policing alone will not be successful over vast territories, as seen today in the war on drugs in South America and Asia.

Today conservation also embraces various components of agro-biodiversity like crop varieties, land races, semi-domesticates and crop relatives. The role of indigenous communities in maintaining agro-biodiversity is stressed by the Global Biodiversity Assessment and the Leipzig Plan of Action, two recently concluded international agreements.

## 5. Applications of biotechnology and its effect on biodiversity

The methods of biotechnology can be applied to the study of virtually any biological phenomenon and will in some cases have practical applications for maintaining biodiversity. Conversely, threats to biodiversity by biotechnology also need to be considered.

### 5.1 Biotechnology for the acquisition of knowledge

In the context of this paper there are two quite different applications of biotechnology or of molecular biology, that are relevant. The first is to use biotechnology as a tool for acquiring knowledge, whilst the second is to use biotechnology to directly intervene in plant and animal breeding, in particular to transfer genetic information from one sort of organism to a particular crop or to a farm animal to make it transgenic.

Today biological research can hardly be conducted without using biotechnology in one way or another. Taxonomy uses molecular markers to identify individual strains of organisms or to identify species, much in the same way as is also done in forensic medicine to identify criminals. This is useful for ex situ conservation of plants and micro-organisms. In seedbanks, genetic fingerprints are used to establish the origin of a seed or the relatedness of one plant variety to another. A rational classification of most micro-organisms has only become possible with these biotechnological methods. This is important to the many collections of micro-organisms that exist around the world.

Biotechnology has also proven useful for following genetic markers in plant and animal breeding. Here animal or plant varieties are crossed by conventional, sexual means. By analysing a few cells of the newly born calf or of the newly sprouted crop, one can predict some of the expected properties of the progeny, by looking at the presence or absence of certain forms of genes. This enables one to predict a phenotypic property, which will only show up later in life, for instance certain characteristics of a cow's milk or the crop's expected resistance to an infectious plant disease. Using in vitro fertilisation of animals, the laboratory test can be done even before the embryo is implanted. This is called pre-implantation diagnostics.

These applications of biotechnology are in general not controversial. Here the public perception is similar to the application of modern biotechnology in medicine, for instance to industrially produced pharmaceuticals, vaccines and diagnostics. It may be noted that the world-wide sales of biotechnology products in 1999 was worth around 13 billion dollars in the medical field and only 1.6 billion in agriculture.

The availability of genome sequences will be a boost to research. The first two complete plant genome sequences determined were those of Arabidopsis and rice. The 120 million base pair (MBP) of the small brassica Arabidopsis were sequenced by an international academic consortium and the data made publicly available as reported by both Adam and also Dennis and Surridge. The 430 MBP sequence of rice was completed only a few weeks later by an industrial group lead by Syngenta and will be available by contract to other researchers as reported by Dickson. Syngenta intends to make the data available free of charge for research directly benefiting subsistence farmers. The public sector sequencing of rice through an international consortium is expected to be completed in 2004. It will hopefully become common practice for companies to make their basic discoveries publicly available, to everyone's benefit. The Monsanto company too has opened up some of its rice sequencing data.

### 5.2 Direct gene transfer to crops and farm animals

Since all genes consist of DNA and the information in this DNA molecule is read in the same way in all organisms in order to make proteins, it is in principle possible to take any (single) gene from any organism and transfer it into any other organism so that the recipient should produce a protein normally made only in the donor. The resulting organism is called transgenic. From the time this simple strategy was devised it took molecular biologists about twenty years until the first transgenic plants were made in 1985. Ten years later the first transgenic crop appeared in supermarkets in the USA, the "FlavrSavr" tomato. In 2000 there were world-wide about 45 million hectares planted with commercial transgenic crops.

Most transgenic crops planted commercially in 2000 were in the US, Canada, Argentina, with smaller amounts in China, Australia, South Africa, Mexico and Spain. Soybean and corn ranked first and second, making up 57% and 22% of the total area planted with GMOs. Cotton and canola accounted for about 5.3 and 2.8 million ha each, whilst only small areas of transgenic potato, squash and papaya were grown commercially. As regards the traits, herbicide tolerance was dominant with 74%, while insect resistance was 19%. According to the ISAAA the amounts of virus resistant crops was quite small. Compared to 1999 there was an increase of 10% in the area planted with GMOs. For corn there was a decrease, presumably because of an anti-GMO-wave that started in Europe in early 1999, Soya and cotton showed an increase.

The reason US farmers have adopted the transgenic crops surprisingly quickly is because of the economic benefits they offer. In most surveys done by different researchers in different parts of the US, the yields were the same or somewhat higher with the new seeds (www.internutrition.ch). The most noticeable difference to the farmers was the saving on herbicides. The US National Center for Food and Agricultural Policy cited an annual saving of 220 million $ to soybean farmers. Gianessi and others also found the new crops needed less frequent sprayings and allowed "no till" management. These benefits mostly offset the initial higher cost of the transgenic seeds, but it is also so that farm profits, with or without modern biotechnology, vary a great deal from year to year and region to region. Clearly these economic considerations only hold for countries with economic structures similar to those of the US, but not to LDCs.

It is important to remember that a large number of transgenic crops are still in the development stage and will only come onto the market in a few years from now. They are likely to show benefits for the consumers and some may be of particular interest to farmers in tropical countries. Two rice varieties with anticipated consumer benefits are those containing Vitamin A or an increased level of iron in the product have been developed by Potrykus and Beyer. Despite traditional preventative measures (distribution of free vitamin A, encouragement to eat more fruit and vegetables) 130 million youths are vitamin A-deficient, 1 - 2 million die annually as a consequence of vitamin A-deficiency and 500'000 turn blind irreversibly every year. A bowl of 300 g of this cooked rice is thought by Gura to be enough to overcome to a significant degree the vitamin A-deficiency. Similarly iron-deficiency, particularly prevalent in pregnant women, can potentially be alleviated by rice containing an increased amount of iron in its endosperm. Such rice varieties have been successfully developed in the laboratory, but are far from commercialisation, for both scientific and political reasons.

For farmers in LDCs the following GMOs may become of interest:

- virus-resistant cassava

- virus-resistant sweet potatoes

- virus-resistant papaya (already on the market in Hawaii)

- rice with increased rate of photosynthesis and thereby a potential yield increase of up to 25%

- rice with increased salt tolerance

- diverse varieties that are partially aluminium-resistant and have the potential to grow in degraded tropical soils

- diverse crops that are more drought-resistant than the usual varieties.

All of these and many more crops have been proven in principle to work in laboratory and glasshouse trials. The practical benefits and risks of the crops need to be assayed in the field and their products scrutinised, like any other novel food. Several lines of transgenic farm animals have been produced, but none have been commercialised. Some lines are made for the pharmaceutical industry to produce drugs in their milk. Others may show improved resistances towards certain infections. Transgenic salmon that grow faster than normal have been developed and have roused considerable concern amongst ecologists. As pointed out by Reichhardt, many environmental issues still need to be clarified in this context. However, it is clear that the transgenic crops that have been commercialised so far have not been seen to have done any harm to either the environment or consumers.

5.3 Native Biodiversity and Biotechnology

Biodiversity in the wild has been massively reduced in the industrialised countries over a long period of time, in Europe for example over several millennia. Hardly any ecosystem is the same here as it was before humans started to clear forests and develop farming. When we look out of the window we see houses, roads and meadows, whilst three thousand years ago the area was covered in beech and oak forests. Even Europe's forests are more like manicured gardens than virgin forests, despite the mystical "naturalness" attributed to our forests, at least in Germanic countries. North America still has far more native, untouched ecosystems, either in the form of protected areas or in less hospitable regions like the North of Canada. Biodiversity has already diminished on a massive scale in the industrialised countries.

Despite many conservation efforts about half of the tropical humid forests have already been destroyed. How then can the rest be preserved, given that the regional population is increasing rapidly, as for instance in sub-Saharan Africa, where a near doubling of the population is expected in the next 25 years? Already today, the per capita food supply in sub-Saharan countries is only 2100 kilocalories compared to 3500 kilocalories in the industrialised countries, so there will be a huge pressure to provide more food as seen by Ndiritu. Even if some food is imported, the vast majority has to be produced regionally or nationally, both for reasons of economy and ecology (e.g. poverty reduction, transport and distribution costs).

Yields of cereals have gone up very considerably in the last forty years. In the LDCs this is primarily a result of the Green Revolution. However, the annual growth increases in cereal yields have slowed down from about 3% to 1% per year as shown by Pinstrup-Andersen and others. For the LDCs they were 2.8% in 1967-1982, 1.9% in 1982 – 1994 and only 1.2% in 1993 – 2020. These lower yield increases of recent years mean that productivity will probably not keep up with demand in the LDCs. The consequence on biodiversity is devastating and means that more land will be required for farming. This land will primarily come from areas with high native biodiversity, in particular the aforementioned tropical humid and dry forests.

Conway concludes that the single most promising way to avoid habitat destruction is to increase farm yields in a process that has been called the second green revolution. Several components will be required to increase productivity: better training and education of farmers (in particular women), more favourable economic and political climate, availability of micro-credits etc. In addition, technical contributions will be necessary too. One such contribution is improved seed, produced either by traditional crop breeding or by modern biotechnology. Reliance will have to be more on the latter, since traditional breeding seems to have reached a yield plateau. So agricultural biotechnology, which is viewed controversially in the public debate, may contribute markedly to conserve biodiversity by preventing the appropriation of native biodiversity-rich land for farming purposes . It should be noted, however, that this technology – like all others – is no panacea. Pinstup-Andersen and Cohen believe that each application needs to be studied carefully in a case by case manner, like any other new technology.

A valid concern is the possible effect of Bt-crops and similar plants on non-target insects. The Bt-crops contain an gene coding for an insecticidal protein originally produced by the soil bacterium Bacillus thuringensis. They were developed to make the plants resistant to a particular, highly damaging pest and have been quite successful in reducing pesticide input when infestation rates are high. In laboratory studies Losey showed that the pollen from Bt-corn could kill larvae of the Monarch butterfly, when a large amount of pollen was sprayed on the larvae's favourite food plant, called milkweed. Subsequent field studies by Sears showed that the Bt-corn caused little or no damage to the Monarch in real agricultural settings. This shows that the impact of transgenic crops on non-target organisms cannot be studied only in the laboratory, but requires farmland experimentation.

A more limited concern, that largely touches Northern Europe, is the conservation of native plants and animals, in particular birds, in farmed areas. The birds' habitats are fields, hedges, roadsides and fallow land where they depend for food on insects and seeds produced by weeds in or near the crops. These seeds are particularly important in the winter months. Computer models by Watkinson suggest that more intense weed control measures may lead to smaller amounts of seeds being available to birds. This effect seems plausible under certain conditions, but depends on weed management regimes rather than on the presence or absence of transgenic plants and therefore is not an issue of biotechnology. Herbicide tolerant beets may allow farmers to tolerate weeds for a longer time and fight them only after sowing. This is made possible by a post-emergence herbicide treatment. More efficient weed management may also make it possible to set aside more land, comments Hodgson. If the lack of food results in a reduction in the bird population, this may according to Johnson lead to an increased number of harmful insects in the fields. It must be remembered that farming the land serves quite different purposes, particularly in Northern Europe. The primary goal is obviously the production of food, but secondary goals, such as conservation of biodiversity and giving city dwellers opportunities for outdoor activities, are also important. For the latter purpose, setting aside more farmland would be helpful. In order to do this, political will and financial incentives are a prerequisite.

5.4 Agricultural Biodiversity and Biotechnology

Possibly not only wild plants, but also old landraces might be threatened by transgenic crops. It needs to be recalled that vertical gene transfer by pollen has always occurred between different old landraces and between different new varieties of crops. Despite this, varieties of apples or cereals have been stable over many years and specific traits have not disappeared. Pollen has always flown. What has become far more precise is the method of analysis. Thanks to gene probes and to GMOs it has become much easier to follow gene flow, since one is no longer dependent on visible traits, but can follow a specific gene. Nevertheless, it is important to preserve landraces and native relatives of crops for their intrinsic value as well as for having starting material for future crop breeding.

Can newly introduced transgenic crops transfer genes vertically to native wild plants and thereby change important characteristics of the wild plants? Vertical gene transfer between cultivars and wild plants has always occurred within the limits of species, if the two types of plants were in close proximity and flowered at the same time. No new problems can be expected from transgenic plants, except if the gene transferred from the GMO to the wild plant significantly increased the fitness of the recipient. This seems rather unlikely a priori, but needs to be studied experimentally as suggested by Ammann, both in the laboratory and the field. Herbicide resistance transfer from a herbicide tolerant, transgenic crop to a close relative can occur in the field, as has been shown for canola by Mikkelsen in Denmark. However, this would be of major significance only if the recipient weed was controlled by this herbicide in this farm setting.

Small farmers in many LDCs use a remarkable number of landraces of many different crops. These are often well adapted to the local climate and topography, and are used to produce foods for different cultural purposes. In the Andes region of South America, dozens of different varieties of potatoes are grown, often side by side on small plots. In Europe different varieties of potatoes are used for the industrial production of chips and for preparing Rösti in the home. Will the traditional landraces disappear when, and if, transgenic crops are introduced by farmers in LDCs? To judge by the European past, the answer will be largely yes, not because of any biological hazard emanating from the GMOs, but because farmers need to produce economically and sell their products. Many old varieties of apples have disappeared in Europe because of the preferences of the food retailers and consumers, who buy just a few varieties. The rapid consolidation in the global seed market too is a concern for the maintenance of agricultural biodiversity: a decreasing number of companies controls the global seed and agrochemical markets. Anti-trust legislation needs to prevent the formation of overly powerful monopolies. This concern is not a consequence of the introduction of agricultural biotechnology, but a consequence of globalisation. New technologies have in many areas, not only biotechnology, made large companies more powerful and more visible. It may be possible that modern breeding methods based on molecular genetics will per se reverse the trend of variety losses, since the insight in genomics may bring back respect for landraces and the need to conserve them.

**6. Social consequences**

The introduction and spread of new technologies generally have social consequences with winners and losers. For biotechnology this has led to intense public debate on many different facets, among them ethical, economic, legal and emotional.

6.1 Economic considerations

One may wonder under what economic conditions biotechnology will benefit agricultural productivity, prevent the expansion of farm land and thereby help the preservation of biodiversity. It is worth remembering that the green revolution, which improved wheat and rice production in Asia, was initiated through work done in the public sector, namely in the Philippines at the International Rice Research Institute (IRRI) and in Mexico at the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), both institutions which belong to the Consultative Group of International Agricultural Research (CGIAR). Today, innovative research in agricultural biotechnology is largely done by a few large companies, with smaller contributions from the public sector. That companies strive for intellectual property rights (IPR) through patenting or other protective mechanisms is understandable and largely unavoidable, if innovation is to be maintained. However, provisions need to be made, so that the agricultural research institutions of LDCs obtain easy access to the patented materials and procedures as well as to knowledge they need in order to improve the position of poorer farmers as proposed for instance by IRRI.

A very limited number of transfers of specific patents has already occurred, such as from Monsanto to the Kenyan Agricultural Research Institute for producing virus-resistant sweet potatoes discussed by MacIlvain or another to IRRI for the promoter genes used in golden rice reported by Normile. This approach, including the possibility of forced licensing, is more practicable than wanting to overthrow the world's patenting system with the slogan "No patents on life". The patenting system does, however, need to be adapted in order to do justice to the complexity of living organisms. It may be noted in passing that the first patent granted for a living organism was given to Louis Pasteur in 1873 for a specific type of yeast.

A new issue arising in the field of IPR is the attempt to protect traditional, indigenous knowledge and preserve biodiversity through new international legislation as reported for instance by Girsberger. This legal instrument is still in an embryonic state of development.

At the level of the individual human being, the lack of food appears to be, and is, largely a problem of distribution: there is not sufficient food available, where it is needed. In addition, the poor simply do not have the money to buy sufficient food. Since in LDCs most of the poor still live on the land, it is there, that more income has to be generated, so that there is not only enough for survival, but a surplus which can be sold on the market. Increasing agricultural productivity is the most effective way to do this and should, according to economists such as Lipton, embrace modern biotechnology as an important component.

6.2 Ethical considerations

The issues involved in the interaction between biodiversity and biotechnology have far-reaching consequences and need to be subject to an open and knowledge-based dialogue in society. The heated public debate, seen primarily in Europe in the last couple of years and which in some circles led to near hysteria, is according to Leisinger not sufficient to solve the underlying problems. The dialogue needs to include many different stakeholders, including farmers of LDCs, diverse scientists, policy makers and communicators. Cultural values involved in farming and food production need to be taken into consideration, just as much as the emotional side of eating and drinking.

A significant aspect of ethical behaviour is openness. Transparent information is required both from scientists in non-commercial settings as well as from industry. Although competition from fellow researchers and from industries does not allow immediately divulging all research results, both groups should make concessions to the interested public and to policy makers. This should be done by scientists personally and would help improve mutual confidence.

Several large projects in biotechnology like HUGO, the Human Genome Organisation, have an "ELSI" component, dealing with ethical, legal and societal implications of biotechnology. This shows that some scientists realise that science cannot be seen as a human activity taking place in a void, without any connection to social and political realities. Ethicists stress that it is the responsibility of scientists to be actively concerned with these issues and that they should take special responsibility in communicating with non-specialists to explain what they know as well as what they don't know. Matrices of criteria have been set up for instance by Mepham to make it possible to ask relevant questions. Who and what may be affected by agricultural biotechnology, what properties like wellbeing, autonomy or justice may or may not be infringed upon. The questions put forward by ethicists need to answered on the basis of concrete scientific knowledge, using comparisons with other, established agricultural practices. Ethicists will have critical and thought provoking questions. However, their answers and attitudes may vary considerably. If they are positive as Comstock, ethicists will suggest pursuing research and application with appropriate caution. There is no easy answer to what the word “appropriate” means, beyond answering questions in a case by case manner to balance benefits and risks. Actively shaping the future and attempting to solve problems always involves risk.

It will be important to see ethics not as a stable set of principles but rather a discursive process, which will be apt to cope up with the growing speed of new developments as discussed by Ammann and Ammann. The Nuffield Council of Bioethics recently came to the conclusion that “The moral imperative for making GM crops readily and economically available … is compelling”, if well-informed governments of LDCs want to introduce them. This imperative should be taken seriously and treated with urgency: every day 20’000 children die of malnutrition and 30’000 ha of humid tropical forest are destroyed.

6.3 A case study: Biotechnology in India

By setting up a National Biotechnology Board in 1982 and a Department of Biotechnology in 1986, the Indian Government has demonstrated its belief in biotechnology. The country has spent 15 million $ on plant biotechnology. Prasantha Kumar Ghosh, chairman of the committee that grants permits for field trials, says he would like to see transgenic crops playing a major role in Indian agriculture. Cotton is of particular interest, since 45% of pesticides used in India are for this crop alone. It is possible that cotton will become the first commercialised transgenic crop, but this is not yet the case. Several NGOs oppose any releases of GMOs, at least as long as the new varieties come from foreign multinational companies, as reported by Jayaraman and by Sharma.

A National Plant Genome Research centre has been established at Jawaharlal Nehru University, whilst in other academic settings there are also many biotechnology groups. The Indian Academy of Sciences joined the Science Academies of China, Mexico, the United Kingdom, Brazil and the USA, to study risks and benefits of transgenic plants and their significance for world agriculture. The final text, which was published in July 2000 is an extensive and differentiated report essentially saying that the world needs these new crops, but that the socio-economic conditions have to be such, that the poorest people in the poorest countries will also benefit.

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