Genetic engineering in agriculture: how does it impact on biodiversity?

Soybean has been cultivated in southern Latin America since the 1980s. The use of genetically engineered seeds and rising soybean prices have reinforced the trend for soybean monoculture in the region. A soybean field in Canindeyú, eastern Paraguay with erosion curves. Photo: E. Dimpl

The majority of the world's plant genetic resources are located in tropical and sub-tropical regions and therefore in today's developing and emergent countries. It is primarily small farmers who preserve and take care of these resources and the related agricultural diversity. As genetically modified crops have also been cultivated in these regions for some 12 years now, the question of their influence on agrobiodiversity arises. Is the impact of genetically modified crops on biodiversity beneficial, detrimental or neutral? We shall use the examples below to discuss this.

An estimated 40 % of the global acreage of transgenic, i.e. genetically modified (GM), crops is to be found in developing and emergent countries, and, in fact, almost exclusively in just six countries: Argentina, Brazil, China, India, Paraguay and South Africa. Four crops account for 95 % of all transgenic varieties planted: soybean, maize, cotton and canola (*see Table 1*). They are grown for industrial purposes or as animal feed. Until now, only two genetically-induced traits have gained commercial importance: herbicide tolerance (HT) in crops and pest resistance through insertion of a gene from the bacterium *Bacillus thuringiensis* (Bt).

Table 1: Estimated global distribution of transgenic crops

a) By crop	Million hectares	%
Soybean	60.0	58.8
Maize	20.1	19.7
Cotton	12.1	11.9
Canola	5.0	4.9
Other	4.8	4.7
Total global acreage	102.0	100.0
b) By selected developing and emergent country	**Million hectares**	**%**
Argentina (soybean, maize, cotton)	18.0	17.6
Brazil (soybean, cotton)	11.5	11.3
China (cotton)	3.5	3.4
India (cotton)	3.8	3.7
Paraguay (soybean)	2.0	2.0
South Africa (maize, soybean, cotton)	1.4	1.4
Other	0.7	0.7
Total developing and emergent countries	**40.9**	**40.1**

Source: C. James 2006

Genetically modified crops – enrichment or contamination?

The example of transgenic maize in Mexico (*see box next page*) illustrates how transgenic plants, when released from the greenhouse, may cross-pollinate with other varieties and with wild relatives. This pollination is irreversible and difficult to limit regionally. British scientists found pollen of transgenic creeping bent (*Agrostis stolonifera*) up to 21 kilometres away from where it had been cultivated. Greater distances were assumed, but not quantified. This makes the coexistence of transgenic crops with non-transgenic crops virtually impossible.

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Local varieties of maize cobs – does the cross-pollination of transgenic varieties pose a threat to diversity?

Photo: Elin Volder Rutle/ The Development Fund.

The case of transgenic maize in Mexico

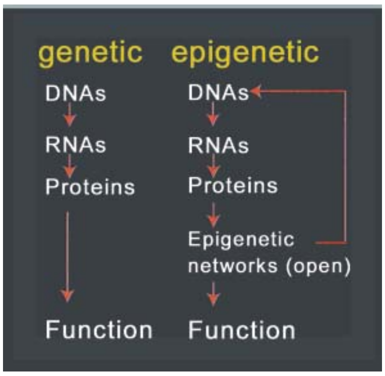
Around 10 000 years ago, maize was discovered and domesticated in the Oaxaca region of what is now Mexico. Over the millennia, the indigenous peoples of Central America have bred a vast number of landraces and created a unique genetic diversity of maize. To this day, such diversity is maintained largely by smallholders who keep cultivating their varieties year after year. Today, Mexico probably has the richest maize gene pool in the world.

With the commercial use of transgenic maize varieties in North America, the government of Mexico issued a moratorium on GM maize in 1998. It banned cultivation of transgenic varieties, but did not take further action to control maize imports. Transgenic maize thus entered the country in various ways. Large North American food imports containing high proportions of GM maize made up the major share. In 2001, scientists found evidence that GM varieties had introgressed into the genome of landraces of maize in southern Mexico.

Another question remains controversial: is the introgression of transgenes a threat to genetic diversity, or an enrichment? The Director of the international maize research institute CIMMYT (2002), referring to the Mexican case, sees this as no different from landraces of maize cross-pollinating, a process that increases and enriches genetic diversity. On the other hand, in 2007 the UN's food and agriculture organisation (FAO) advised all international agricultural research centres to do everything possible to avoid unintentional transgenic introgression into their *ex-situ* gene bank collections. There is evidently no consensus at present on how to deal with this problem.

Molecular biology provides new insights

Molecular biology provides new insights into the subject. Scientists have pointed out that the regulation of living organisms is much more complex than commonly assumed, that the development of traits goes beyond individual genes, and that traits are not static but dynamic, in other words can change over time. They are therefore speaking of a paradigm shift – from genetics to epigenetics. The doctrine of "one gene – one trait" is considered obsolete. According to more recent scientific findings, cell regulation and trait development are controlled by a network in which DNA is involved but does not play an exclusive role. It is a network in which feedback to DNA is possible (*see diagram*) and in which acquired traits can be stored and passed on.



Genetic and epigenetic theories of information processsing (Strohman 1997)

The risk of disturbing this network of cell regulation by introducing foreign DNA is an area in which there has been little research to date. However, various unexpected phenomena and unintentional changes have been observed. For example, genetically modified soybeans were found to have up to 20 % higher lignin content than normal. This higher lignin content has a negative influence on heat tolerance, which in turn results in lower yields of transgenic soybean under heat stress. Thus, on the basis of current knowledge, it cannot be ruled out that disturbances in the organism as a whole may be created, sometimes with a substantial time lag. If this holds true, genetically engineered crops contain unknown risks and the unintentional introgression of transgenes must be considered a contamination for plant genetic resources.

Herbicide tolerance is seen to have an effect on biodiversity

Transgenic soybean varieties have been grown in Argentina since the mid-1990s. The introduction of these varieties has enormously accelerated a trend that already existed: the large-scale expansion of monoculture cultivation of soybeans. The plants are resistant to the herbicide glyphosate, allow fully-mechanized production and require less agricultural skill than conventional varieties. Within ten years (1994-2004) the acreage under soybean has increased from 6 to 14 million hectares, and the share of transgenic soybean in the fields from zero to 99 %. The Argentine government aims to increase the acreage by another four million hectares by 2010.

In terms of the national economy, this drastic change to land use and farming systems in Argentina (*s. Table 2*) would initially appear to be positive, but it has had a negative impact on food production and the diversity of cropping systems. Rice and potato cultivation have suffered a reduction of 40 % and 38 % respectively. Even higher losses have been observed with vegetables, and a similar trend has been observed with products such as milk, eggs and meat. The mixed farming systems practised by smallholders are gradually disappearing and are being replaced by large monocropped fields. Above all, smallholders and indigenous peoples such as the Guaraní (*see also the Issue Paper on "Stevia" in this series*) are becoming impoverished and their traditional knowledge is being lost.

Table 2: Land newly planted with soybeans – land use changes in Argentina (1996-2004)

Land use before soybean production	Additional soybean area in %
Major crops:	
wheat, sorghum, maize, sunflower	25
Other crops:	
rice, cotton, oats and beans etc.	7
pasture and forage production	27
forest and savannah	41

Source: Benbrook 2005

Does Bt-technology have a positive effect on biodiversity?

Bt technology is used to produce transgenic plants – cotton, for example – that has the Bt toxin in its DNA. Most insects that eat the Bt toxin die, making chemical pesticides unnecessary. Experience with Bt-cotton in the early years was very promising. Many studies showed that pesticide use was substantially reduced, alleviating damage to insect fauna, decreasing costs of production, and improving net incomes.

Meanwhile this positive picture has changed. For instance, in a study of 481 farms in 5 provinces of China, researchers from Cornell University in the USA found that the majority of farmers had to treat their cotton fields 15-20 times more often than in the early years of growing Bt cotton to kill secondary pests, in particular mirids (*Miridae*). Mirids are relatively resistant to Bt toxins (Wang et al. 2006) and researchers believe they were kept in check before the switch to Bt varieties by regular use of pesticides. Farmers now spend the same amount on pesticides as neighbouring non-Bt growers, in addition to having to pay about 2-3 times more for Bt seed. A similar finding is reported from the Makhatini Flats, the leading cotton growing area in South Africa, and a comprehensive evaluation of growing Bt cotton in developing countries calls into question whether it is economically advantageous (Smale et al. 2006). Furthermore, the effect of Bt toxins on beneficial insects and soil microorganisms is not yet clear. To sum up therefore: based on current knowledge, the impact of Bt technology on biodiversity is at best neutral.

Concentration in the seed supply sector – a threat to genetic diversity

Within the past 25 years there has been unparalleled concentration in the seed sector that is responsible for commercial breeding and propagation. In 2006, over half of the global seed market was supplied by only ten seed corporations. As far as transgenic crops are concerned, the market is cornered by just one company (Monsanto), which provides seed directly or indirectly for approximately 90 % of the total area under transgenic crops. Biotechnology has not caused the monopolization of the seed sector, but it has accelerated and reinforced the process. One main reason for this is that the breeding costs for GE crops are extremely high and the necessary investment can only be borne by larger companies. Conversely, to cover these costs a standardized variety or a whole cropping technology has to be distributed as widely as possible. This development creates dependency among farmers and leads to genetic uniformity of cropping systems as reported from the United States, for instance, where farmers say that it has now become virtually impossible to find high quality, conventional varieties of corn, soy and cotton seed.

Another consequence is the increasing control of genetic resources by a few companies through patents, licences and the like. In the past, genetic material for breeding purposes was in the public domain. Today, it has increasingly become private property, accessible only with the permission of patent holders. This gives them have a strong influence on breeding programmes and strategies and on maintenance of varieties. Today, the concentration in the seed sector is probably the greatest threat to the diversity of agricultural crops.

Conclusions and the way forward

Genetic engineering has accelerated the industrialization of agriculture and thus amplified the negative impact of farming on biodiversity. In addition, it holds new, unknown risks. The introgression of genetically modified plants into non-transgenic varieties and races poses a potential threat that is currently impossible to predict.

Demonstration against GMOs in Stuttgart.
Source: http://www.gentechnik-freie-landwirtschaft.de

Agricultural genetic engineering is usually justified with the argument that it can achieve a quantum leap in intensification of agriculture and accelerate breeding of varieties. So far, no evidence of this has been seen. Most of the progress in plant breeding (yield potential, drought resistance and salt tolerance) has been achieved by conventional methods.

In both economic and ecological terms, agricultural genetic engineering does not fare better than other innovative technologies that promote agricultural intensification. Particularly smallholder cotton production provides good examples of this. Integrated pest management (IPM) (Russel and Kranthi 2006) and organic agriculture (Eyhorn et al. 2007) are economically competitive and environmentally friendlier than Bt technology as they work with reduced or no synthetic pesticide input, and they maintain biodiversity.

Marker assisted selection (MAS) is another innovation that merits attention. Gene-markers are used to identify desired traits more easily. This method can be used as early as the seedling stage of a plant and it also allows wild relatives to be included more easily. It has upgraded and accelerated classic breeding and has become standard practice with every major seed breeding company.

Biodiversity is a strategic resource for the future and therefore indispensable common property. Intensification of agricultural productivity must not proceed at the expense of biodiversity, but instead must harmonize with it. The fact that this is possible is demonstrated by innovations such as marker assisted selection, integrated pest management and organic agriculture – methods that are more in line with the aims of sustainable intensification of agriculture.

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Further information:

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