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Genetically modified insect resistant crops with regard to developing countries

Abstract
Using existing literature, this report summarizes ecological and economical aspects of the cultivation of genetically modified insect-resistant varieties of maize, rice and cotton. It will show that the growth of these crops by smallholder farmers in developing countries can be beneficial for their earnings, their health and also for the ecosystem.

Agriculture in general leads to ecological disturbances as wild plant communities are replaced by monocultures of crop plants. In order to obtain sufficiently high yields, fertilisers are used and weeds combated by herbicides and tilling. Insect attack and fungal infections have to be minimised, both achieved conventionally by the application of pesticides which have adverse effects on the agricultural ecosystems. An alternative approach is to use genetically modified (GM) crops resistant to pests. It is just over ten years since the first GM crops were introduced yet they are very popular with farmers. In 2006 approved GM crops were grown globally on 102 million hectares, more than 5% of all arable land; the increase between 2005 and 2006 alone was 13%. Some 90% of those benefiting were resource-poor farmers from developing countries whose increased incomes from biotech crops contributed to the alleviation of their poverty. The Nuffield Council of Bioethics stated 1999 that *"GM crops had a considerable potential to improve food security and the effectiveness for the agriculture in developing countries*".

Whether the growth of GM crops is more economically rewarding and less damaging to the environment than the cultivation of their conventional counterparts with conventional protection by agrochemicals needs to be considered on a case-by-case basis. The present report deals with three important crops grown in developing countries: maize, rice and cotton, all with genetically engineered resistance towards feeding insects. This has been achieved by the expression within the crop plants of proteins (Bt-proteins) derived from the bacterium *Bacillus thuringensis*. Over 200 different Bt-proteins toxic to selected insects have been identified in various strains of this bacterium. For 40 years Bt-proteins have had a safe history as bio pesticides preparations and are approved for organic farming. Rats fed with very high doses of Bt-proteins showed no detectable toxic effects whereas synthetic pesticides, such as organophosphates and chlorinated biphenyls. are toxic. The high price of Bt-preparations, however, makes them expensive for use on commodity crops and they represent less than 2% of pesticides sold world-wide. Synthetic pesticides kill a very broad spectrum of insects, i.e. the target pests as well as beneficial insects, whereas Bt-crops kill primarily those insects attacking the crops.

Seeds incorporating Bt technology are particularly suitable for smallholder farmers, because they do not require the equipment and knowledge necessary for pesticide applications, and reduce farmers' exposure to insecticides, particularly for those using hand sprayers.

Maize
Worldwide, maize is the leading staple in tonnage terms. with two-thirds of the global hectarage grown in developing countries. It is noteworthy that the yields of maize harvested per hectare in the Corn Belt of the US can be 20 fold higher than that of resource-poor subsistence farmers in developing countries. Although most maize is used as animal feed, it is a staple food in many countries, particularly in sub-Saharan Africa and South Asia. For example, the consumption of maize in Kenya has been reported to be 400g per person per day. In such countries it is imperative for food security that maize harvest yields are improved. Decreasing the harvest losses caused by insect pests is a major factor in yield improvement and stability.

On a global basis, the most important insect pests of maize are the larvae of various moths (corn borers). In temperate areas of America, and also more recently in Europe, rootworm larvae which damage roots have emerged as serious maize pests, with the yield losses in fields infested with rootworms as high as 50%. While rootworms can be combated by spraying organophosphates onto the soil, stem borers are difficult to control by pesticide spraying as the caterpillars penetrate into the plant. The application of pesticides has thus to target the caterpillars during the very short time between their emerging from the egg and entering the maize plant. Bt-maize, by contrast, has the advantage of the caterpillars being targeted when they feed on the plant and are so prevented from entering the stem. Although combating some pests will increase the population of others, the global deployment of Bt-genes to control maize pests has been estimated to have the potential of substituting 40-50% of the insecticides currently in use.

During the past ten years, hundreds of million people have consumed products from GM-maize and it has been widely used as animal feed. Yet, as discussed in an earlier report of our commission (*Are there hazards for the consumer when eating food from genetically modified plants?*), there is no evidence of the consumption of GM maize or its products being harmful to health. Moreover, there is clear evidence that GM maize offers the advantage of being much less subject to contamination by mycotoxins such as fumonisin and aflatoxin, toxins produced by fungi that infest maize cobs and which cause serious illnesses in man and animals. The invading fungi are opportunistic, primarily infecting kernels damaged by caterpillars; contamination by these powerful toxins can be so high that harvest products have to be withdrawn from the market. For subsistence farmers, e.g. in parts of Africa, the toxins cause grave health problems, particularly for children. The significantly lower mycotoxin contamination of GM maize is due to the fact that the cobs have fewer injuries. Thus, Bt-maize offers a critically important advantage for consumers concerned about food safety.

So far, maize Bt seeds have been distributed as hybrid varieties giving high yields, but the harvested grains cannot be used as farmer-saved seed. Critics of biotechnology often offer this as a reason why, in developing countries, Bt seeds are not suitable for smallholder farmers who mostly use farmer-saved seeds. However, hybrids are the predominant seed types in many developing countries. In China, the largest producer of maize after the USA, where maize is grown by 105 million farmers with an average holding of 0.23 hectare per farm, 84% have adopted hybrid seeds since they offer a higher return. For areas such as Central America and West Central Africa, where most of the maize is grown by subsistence farmers with farmer-saved seeds, non-profit organisations are called upon to introduce Bt genes into local varieties so that these farmers may also profit from Bt technology.

Rice

World-wide, rice is the principal food for nearly two billion people, with the main producers being China, India and Indonesia. In these countries, rice is mostly grown by about 250 million smallholder farmers. Again, major insect pests are caterpillars such as stem borers and leaf-folders. At present, the productivity of rice plantations depends heavily on chemical inputs. The introduction of conventional pesticides about 30 years ago had a devastating impact on insect diversity, drastically reducing the populations of fish and crabs in the rice fields. Many companies and institutions in the world, e.g. in Iran and China, are developing genetically modified insect-resistant rice. Bt-rice cultivars have already been field-tested in Iran, China and Costa Rica, and the first commrcial release has been in the Iran. Field studies indicate that the introduction of Bt-rice has the potential for decreasing the amount of pesticides sprayed on the fields by more than 50% together with considerable increases in harvest yield.

Cotton

Cotton is grown in developing countries mainly by smallholder farmers. The harvest is particularly threatened by insect pests such as the cotton bollworm, caterpillars, feeding within the fruit where the cotton fibres are produced. Without treatment, these pests can destroy most of the harvest. Conventionally, they are combated by spraying organophosphate or pyrethroid pesticides. More pesticides are applied per hectare of cotton than to any other crop with the number of sprayings necessary per season varying from 2 to 12, but sometimes as high as 30. Despite major expenditure of pesticides, cotton cultivation had totally collapsed in various regions of the world because of extremely high infestation levels.

For the past ten years, genetically modified cultivars containing a Bt-protein toxic to the cotton bollworm have been available. Their commercial introduction has been very successful: by 2005, Bt-cotton was grown on 28% of the global hectarage of cotton. Whereas the Bt-cotton technology was originally commercialised by a single company in the US, it is now also distributed by a range of companies and institutions in China, India and elsewhere. In China in 2006 more than 65% of the cotton was Bt-cultivars, in India 40% and in South Africa as much as 85%.

Ecological aspects

Experience with traditional crops shows that, through hybridisation, they can give rise to weeds requiring special cultural practices for their elimination. It is well established that gene flow occurs between both GM-cultivars and non-GM crops and their wild relatives. Cultivars of maize, rice and cotton sown as crops do not have sufficient biological fitness to survive in natural habitats; in most cases the incorporation of a few additional genes is unlikely to alter the fitness of a cultivar in a natural ecosystem. Maize has wild relatives only in Mexico and Central America whereas the wild relatives of cotton and rice are more widespread. So far, no transgenes have been observed to escape from maize or cotton to a wild relative, there permanently to initiate a selective advantage. In the wild, insect resistance could offer such a selective advantage but insect resistance mediated by a single gene is unlikely to persist. In the case of Bt-rice, particularly with modern rice cultivars designed for dry-land agriculture, special attention must be paid to the question of the possibility of gene flow to weedy wild rice relatives. It is surely relevant for such scenarios that, for more than 30 years, a very large number of rice cultivars have been grown into which single genes conferring resistance to certain insects had been introduced by conventional breeding. There are no known cases in which wild or weedy rice populations have become more competitive as a result of hybridisation with these cultivars.

Some years ago it was reported in a laboratory experiment that feeding Bt maize pollen caused considerable toxicity to Monarch butterflies and that survival of the species was threatened by this GM crop. The report provoked so much public anxiety that the European Union passed a moratorium lasting several years on the approval of GM-crops. Extensive field studies, subsequently carried out by numerous investigators, clearly demonstrated that the cultivation of Bt-maize has no measurable impact on Monarch butterflies. A large number of studies with Bt-maize, rice and cotton, performed in several countries, have all shown that the populations of many non-target insects are higher in fields of Bt-cultivars than in fields of conventional crops regularly receiving applications of broad-spectrum pesticide.

There has been concern that Bt-proteins from the litter of plants and root exudates persist in the soil and have an impact on its fauna. Taking into account that agricultural soils are in any case highly modified by conventional cultivation, and particularly by tilling and the application of fertilisers and pesticides, the impact of Bt-crops on the fauna in the soil has been shown in extensive studies, including bioassays, to be irrelevant.

As mentioned earlier, Bt-proteins are toxic only to selective insect pests. Combating those pests which are insensitive to the Bt-toxin means that in many cases the cultivation of Bt-cultivars still requires the application of pesticides although the number of pesticide sprays required is mostly much lower than with conventional cultivars. Decreases in pesticide applications are beneficial not only for the environment but also to farm labourers. Spraying chemical pesticides is a considerable health hazard, especially if hand sprayers are used. A survey in China revealed there were formerly on average 54 000 poisoning incidents annually, including 490 deaths due to the use of pesticides, and that the introduction of Bt-cotton cultivars reduced this health risk substantially**. These facts provide overwhelming support for the beneficial effect of Bt-crops cultivation, both for the environment and for the health of the farm labourers**.

Economic aspects

Since the seeds of Bt-cultivars are more expensive than their conventional alternatives, a farmer will have to decide whether infestation by pests is high enough to make the purchase GM seeds profitable. Although the returns for using Bt technology can result in reduced labour and pesticide costs, as well as increased harvest yields, there remain situations in which the expenditure for Bt-seeds does not pay off.

The fact that in 2006 more than 80% of cotton in the US and 90% in Australia were planted as Bt cultivars clearly demonstrates that the Bt technology can indeed be profitable for farmers.. The decision of whether or not to use such seeds was made by individual farmers on commercial grounds.

This also applies to many developing countries. In China, where cotton is grown by farmers with an average holding of 0.4 hectares, about seven million farmers have already adopted Bt-cotton. Bt technology is reported as being profitable because it leads in many cases both to a substantial decrease in pesticide use and to a yield increase. In India, where cotton contributes 30 % of the national agricultural gross domestic production and is grown mainly by smallholder farmers, the infestation of cotton fields by insect pests is very high and the average yield per area only about half of the world average. In India, only four years after the commercial release of Bt cotton, more than two million farmers have decided to grow it, with an increase of 190% during the last year. As reported, most, although not all of them, derived substantial profit as a result. Future success depends on the introduction of locally adapted varieties. In both China and India the distribution of Bt technology is no longer restricted to multinational companies but increasingly involves national companies and institutions, resulting in more competitive pricing.

In South Africa 44% of white maize (used as food) and 50% of yellow maize (used for fodder) have been planted in 2006 as Bt variety with an almost threefold increase over the last year.

The examples show clearly that Bt technology can indeed be valuable in economic terms to smallholder farmers with relatively small fields in developing countries as well as to the large farms in developed countries.

There is, however, the possibility that pests may become resistant to Bt-toxins as has happened in the past with the extensive use of organophosphates and pyrethroids. Although the evolution of resistant pests will not cause major ecological problems, it might gravely affect the economy of farmers and seed companies. In order to prevent such resistance, countries like the US have adopted insect resistance management programs which include providing refuges of non-GM crops or other hosts. This ensures that susceptible insects are available in sufficient numbers to mate with any resistant survivors from Bt fields, so preventing the build-up of resistant insect populations. Thus far this system has worked well; almost all farmers obey the rules and several recent studies have failed to find resistance. Smallholder farmers do not have such problems, because they usually have several small fields with diverse crops

World agriculture must continue to fulfil the food and fibre needs of the growing human population as well as rectify the existing widespread malnutrition. **To achieve this aim, pest control will have to rely on integrated pest management practices which include crop rotation, biological control, Bt technology and the sparing use of pesticides. Bt technology has shown itself to be a valuable contribution to knowledge-based agriculture.**

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For the sake of brevity only a small selection of references is listed here. These references and very many others are contained in a collection of pertinent literature which is available at the website
http://www.akademienunion.de/publikationen/literatursammlung_gentechnik/english.html

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Prof. Hans-Walter Heldt, Universität Göttingen (Co-ordinator)