Environmental impact of biotech crops

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ABSTRACT: Agriculture will inevitably always have a significant impact on the environment. For biotech crops to be accepted by the regulatory process, it is a statutory requirement in most countries to complete an environmental impact assessment. The assessment includes determining the frequency and potential impact of gene flow by pollination, the effects on friendly nontarget organisms within the environment, the consequences of introducing particular genes, and, in some countries, a consideration of the effect of biotech crops on wildlife biodiversity. Assessing environmental impact raises many important challenges, because frequently we are required to make assessments of a kind that have rarely been carried out for conventionally bred crops. Debates about how we measure environmental impact most effectively have highlighted the illogicality of detailed environmental assessments of biotech crops and little or no comparable assessment of conventionally bred crops. It is important that all kinds of agricultural crops are evaluated against an evolving vision for the future of agriculture and the environment over the coming decades. Biotech crops have the potential to aggravate or to alleviate the environment of the future. This can be through direct effects of the crop on the environment or through changes in management required to grow them. Our challenge is to develop biotechnology actively for the benefit of humankind and the environment.

Key Words: Biotechnology, Environmental impact, Gene Transfer, Genetic Transformation, Herbicide Resistance, Regulations

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Introduction

There have been significant improvements in crop productivity during the last century. Wheat yields are now two to three times what they were 80 yr ago. Part of this increase is through plant breeding and genetic improvement, and part is from the use of fertilizers and from improved chemical control of pests, diseases, and weeds. During the course of conventional plant breeding, there has been a desire to increase the choice of genes. Disease resistance genes, for instance, have frequently been obtained from plant species that are relatives of the crop. Many sophisticated plant-breeding methods have been developed over the last 40 yr, including induced mutation and polyploidy. All of these methods have become useful tools for the plant breeder. During the last 15 yr, plant biotechnology has made a further step: it is now possible to introduce genes into crops from a wide range of different classes of living organisms. This is providing an even wider choice of genes for modifying crops in novel ways.

There are, throughout the world, vigorous discussions about the environmental impact of biotech crops (also called genetically modified [**GM**], or transgenic, crops). The objective of this article is to reflect on how we assess environmental impact in biotech crops and to discuss some of the challenges raised by this process.

What Biotech Is About

Conventional plant-breeding methods move genes into crops by pollination. Because of sexual incompatibility constraints, it is only possible to successfully pollinate plant species that are related to the crop to be modified. Various techniques have been developed, (e.g., ovary and embryo culture) over the past few decades to move genes across sexual barriers (Hayward, 1993). For those people who are concerned about the principle of moving genes across sexual barriers, it is worth noting that the application of these invitro techniques to conventional plant breeding has made it possible to achieve hybrids that would not normally survive in nature.

Modern biotech breeding makes it possible to isolate genes from any class of living organism and introduce them into most of our crop plants. Genes transferred from bacteria, for instance, need to have promoters or gene switches that control their expression in the crop

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plant. Temporal and spatial expression of introduced genes are both important to achieve efficient and productive crop plants and to minimize undesirable impacts on the environment.

The result of biotech breeding is that it provides an even wider choice of genes for crop improvement. We can now think in terms of introducing novel kinds of pest and disease resistance; a variety of oil modifications to provide sustainable supplies of oils for different purposes (e.g., food, lubricants, and plastics); and even the modification of plants for the production of speciality products, including pharmaceuticals.

The diversity of genetic changes now possible and, potentially, the speed at which these changes can be brought about, raise many challenges for managing the production of these crops in practice and for assessing their impact on the environment.

Assessing Environmental Impact

The precise procedures used to assess the environmental impact of biotech crops vary from one country to another. However, the information used to make that assessment is similar. It is important to note that biotech crops are one of the first technologies in which safety or risk assessment is carried out proactively. For some technologies of the past, it was usual to respond when things went wrong. If a train was found to be dangerous in some way, the problem was identified through experience and safety procedures were adopted accordingly. Proactive (preventive) safety assessment has many advantages, but it tends to sensitize people to all of the things that could go wrong, without counterbalancing the problems with an awareness of benefit.

In assessing environmental impact, the following questions must be addressed:

1. What is the function of the gene of interest in the original donor organism? For example, it was important to learn about the *Bt* (*Bacillus thuringiensis*) insecticidal genes used in Bt insecticidal sprays over the past three to four decades.
2. What is the function of the gene in the modified plant? The most informative comparison is between the biotech crop and the unmodified crop plant genotype from which it was derived. The difference between the two may only be one or two genes, so it is possible to assess the effect of the introduced genes on plant phenotype and environmental impact, with a precision that is impossible for most crops improved by conventional plant-breeding methods. Generally, in conventional breeding, little is known about the gene(s) introduced to modify a particular plant trait, so conventional plant varieties cannot be regulated with the degree of precision now expected for biotech varieties.
3. Is there evidence of toxicity and allergenicity? Comparisons are made with databases of known toxic or allergenic substances and, when necessary, animal testing is carried out.
4. Are there nontarget effects? Assessments are made of the effects that a biotech crop has on friendly organisms within the environment. In some instances, this is by testing the effect of the synthesized gene product on organisms in the environment, but it can be by observation in field experiments where the regulatory authorities require direct measurements of ecological impact.
5. Are there changes in weediness or invasiveness? Weediness is persistence in an agricultural environment and invasiveness is the ability of crop plants to become dominant in natural habitats.
6. What is the likelihood of gene transfer to other organisms? The most likely cause of this is by pollination between the crop and other crops or related wild species.

I shall discuss some potential environmental impacts in detail.

Gene Transfer by Pollen

Over the past 13 yr, I and others have carried out extensive pollination studies to determine the frequency of cross-pollination at different distances. The frequency of pollination is determined by two principal components. The first is the distance pollen will travel. This, of course, is influenced by the way pollen is transported (e.g., insects, wind; Scheffler et al., 1993, 1995). The second is the sexual compatibility between our crops and related plant species (Scheffler et al., 1994; McPartlan and Dale, 1994). Both of these factors are now quite well understood and the regulatory authorities are using these data to guide them in assessing environmental impact. Cross-pollination and gene flow are innately not hazardous; pollination already happens between sexually compatible crops and between crops and wild populations. The extent of any environmental impact from gene flow is determined by the nature of the gene transferred and the characteristics of the receiving plant populations. For example, if a transferred gene confers cold tolerance to a receiving population, it could potentially change the invasiveness and persistence of that population. Studies are also in progress to assess the characteristics of wild populations that could potentially be pollinated by biotech crops (Raybould et al., 2000). Questions are being asked about the environmental factors constraining those wild populations and the nature of any ecological impact if genes were transferred to them.

Nontarget Effects

The potential effects of biotech crops on friendly organisms within the environment has been debated actively in recent months, since the report that Bt corn pollen sprinkled onto milkweed leaves had an adverse effect on monarch butterflies (Losey, et al., 1999). Subsequent more-detailed studies have indicated that this effect was not borne out in field tests. Pollen concentrations necessary to cause this effect are only likely to occur in a very small area of plants around the field perimeter. However, the monarch butterfly example does remind us of the importance of modifying plants in ways that minimize undesirable effects on friendly organisms. We need to strive to achieve targeted temporal and spatial expression of introduced genes, to minimize undesirable effects on friendly organisms. It is important to remember that agriculture and food production will always have a significant effect on the environment and our objective must be to try to minimize this impact.

When assessing the acceptability of the nontarget effects of biotech crops, we are faced with the question of a baseline level of acceptance. In many respects, the only reasonable baseline is what is already happening in conventional agricultural practice with traditionally produced crop varieties. However, some would argue that the widespread use of certain insecticides or herbicides is having an undesirable effect on the environment and that we should set our standards higher. The problem with this approach is that the environmental impact standards for biotech crops may be set substantially higher than those for conventionally bred crops. Therefore, the future of biotech crops may be penalized unfairly.

Wildlife Biodiversity

During the last 30 yr in the United Kingdom, there has been a decline in the numbers of certain bird species. This is believed to be associated with the removal of hedges, trees, and ditches; with the move from spring-sown to winter-sown crops; and with improvements in pest, disease, and weed control. The result of these changes is that there are fewer left-overs (i.e., a range of plant species, weeds, and plant debris) and habitats available for supporting a diversity of food chains. The evidence I have at hand for this is principally for the United Kingdom (JNCC, 1977), and I do not have comparable figures for North America. In the United Kingdom, there is now a requirement to determine the potential effect of biotech crops on wildlife biodiversity. This question is particularly challenging in the United Kingdom because over 70% of our land area is farmed in some way. The comparable figures for the United States of America is approximately 50% and for Canada, 8%. The consequence in the United Kingdom is that whatever we do to our agricultural environment is likely to have a more significant effect on the wider environment.

Assessing the impact on wildlife biodiversity of biotech crops and not of conventionally bred crops is, in my view, illogical. If we genuinely have environmental impact questions about biotech crops, it is surely also sensible to ask similar questions about conventionally bred crops. There is also the issue of what is our baseline of acceptance for biotech crops: is it that of standard agriculture, or is it some different ideal?

Antibiotic Resistance Genes

Antibiotic selectable marker genes are used frequently in the process of inserting genes into crop plants (transformation). The most commonly used antibiotic resistance genes are kanamycin and ampicillin resistance. Two issues are relevant in assessing the impact of this. One is the likelihood of antibiotic resistance gene transfer between feed crops and gut microflora, and the second is the contribution of any transfer to increasing the frequency of those resistance genes in nature. The general conclusion to date from these kinds of analyses is that, if gene transfer from feed to animal gut microflora happens, it is an extremely rare event. Both of these antibiotic resistance genes are frequent in nature; therefore, it follows that rare transfer to gut microflora will contribute only a negligible amount to their increased frequency in nature. It is also argued by some that ampicillin resistance is the last line of defense in the treatment of certain human diseases, and, therefore, even if gene transfer to gut microflora is rare, it is a risk that we should not take.

From the discussions in Europe, it is clear that opinion is moving away from the use of antibiotic resistance genes. Various reviews of the subject have now concluded that their use in general should be avoided or removed. The view of the U.K. Royal Society report was as follows: “We believe that it is important to encourage further research into alternatives to antibiotic resistance marker genes and that it is no longer acceptable to have antibiotic resistance genes present in a new GM crop under development for potential use in foodstuffs. In particular, researchers in both academia and industry should not produce GM plants containing genes that confer resistance to those antibiotics that are used to treat infections in animals or humans. The Government’s advisory committees on GM crops (ACRE and ACNFP) have both made recommendations to this effect” (Royal Society, 1998).

Regulatory Challenges

It is usual, in the regulatory decision-making processes in various parts of the world, to ask many more questions about the environmental impact of biotech crops than of conventionally bred crops. This is logical and sensible to the extent that we need to develop a familiarity and experience with crops that have been modified in new ways. However, if we are asking serious environmental impact questions about herbicide-tolerant biotech crops, for example, then surely it is also sensible to ask those same questions about herbicide-tolerant crops from conventional breeding.

Biotech crops are assessed by the regulatory authorities case by case. This approach has many advantages. Its disadvantage, however, is that the assessment can lack vision and be influenced by the first-come, first-served principle. For instance, the first herbicide-tolerant biotech crop to come forward for regulatory approval is more likely to be accepted than the fourth request. This is because of concerns about gene flow and the accumulation of herbicide tolerance in weed species. However, the fourth herbicide-tolerant crop may actually be better for the environment.

In the United Kingdom, we have recently set up a new commission, called the *Agriculture and Environment Biotechnology Commission*. The aim of this commission is to stand back from the day-to-day, case-by-case workload in considering commercialization proposals, to ask visionary questions concerning agriculture and the environment over the next 20 to 30 yr. This will, without doubt, be a very challenging exercise for all involved.

Implications

There have been significant improvements in crop productivity during the past 80 yr through plant breeding and changes in agronomic practice. There is a continuous desire in plant breeding to widen the choice of genes for important agricultural characteristics, including pest resistance, disease resistance, and crop quality. The potential to produce novel biotechnology crops has led to the development of more-comprehensive testing of environmental impact than for conventionally bred crops. There are several significant regulatory challenges associated with establishing a baseline of acceptability of environmental impact because food production will inevitably impact the wider environment. Biotechnology is innately neither good nor bad. It has the potential to alleviate or aggravate the impact of agriculture on the environment. The challenge for all of us is to develop, supply, and manage biotechnology for the benefit of humankind and the environment.

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