Transgenic Agriculture: A Tool or a Threat for Integrated Crop Management?

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Introduction

Agricultural crops are the product of several centuries of plant breeding where desired traits have been selected to enhance yield, disease resistance, quality and agronomic performance. Plant breeding techniques have become increasingly sophisticated since 1900 and have routinely employed techniques such as cell fusion (since 1909), mutation via X rays (since 1927) and embryo rescue (since the 1960's). The latest technique to be introduced to facilitate plant breeding is genetic engineering, by which genetic material from other organisms is inserted into a plant to allow it to express novel traits. Such plants are known as Genetically Modified Plants (GMPs) or shortly transgenic plants.

The "first generation" of Genetically Modified crops (GE crops) focuses on agronomic traits to reduce crop losses due to pests and to reduce pesticide use. As expansion of transgenic crops continues, a shift will occur from the current generation of "input" agronomic traits to the next generation of "output" quality traits. Despite a number of benefits of current GE crops, there are concerns regarding their potential adverse effects on human health and the environment, and their production and consumption have been subjected to strict regulation in many countries.

Today the widespread application of conventional agricultural technologies such as herbicides, pesticides, fertilizers and tillage has resulted in severe environmental damage in many parts of the world. Integrated Crop Management (ICM) arose from the recognition of the need for sustainable and profitable agricultural production systems and concerns about environmental stewardship. ICM programs provide integrated plans for management of soil fertility, soil and water resources, pests, and crop production in a way that sustains agricultural profitability and promotes conservation of biological diversity.

The use of GE crops may have potential benefits for farmland wildlife, particularly if their use results in better targeted or lower use of agrochemicals. On the other hand, the introduction of GE crops may permit changes to land use and management, which can be detrimental to wild life. Therefore, the potential impact of a transgenic plant must be carefully analyzed and proper risk management procedures which should always be incorporated into risk assessment, must be applied during transgenic agriculture. In addition, risk communication has to play a central role in ensuring that all stakeholders, i.e. the public, the industry and scientific community, are jointly aware and convinced of the care being taken with the assessment procedure.

Present Status of Commercial Transgenic Agriculture

GE crops are currently being grown in commercial agriculture in several countries, particularly the United States, Argentina, Canada and China. At present several basic commodities dominate the market for GE crops: soybean, corn/maize, cotton, canola/rapeseed, potato, squash, and papaya. Globally in 2000, transgenic soybean occupied first place at 25.8 million hectares, with transgenic corn in second place at 10.3 million hectares, transgenic cotton in third place at 5.3 million hectares, and transgenic canola in fourth place at 2.8 million hectares. Global area of transgenic cotton increased 1.6 million hectares, from 3.7 million hectares in 1999 to 5.3 million hectares in 2000-this was equivalent to a year-over-year increase of over 40% in the global area of transgenic cotton. The most significant increase was reported for the USA where the percentage of transgenic cotton increased from 55% in 1999 to 72% in 2000. China is reported to have significantly increased its transgenic cotton area to more than 10% of its national cotton area, and most modest increases have been reported for Mexico, Australia, Argentina, and South Africa (James, 2000).

The most widely planted GE crops concern only one agronomic trait, though a few varieties incorporate two traits. During the five-year period of 1996-2000, herbicide tolerance has consistently been the dominant trait with insect resistance being second. It is noteworthy that the area of herbicide tolerant crops has increased between 1999 and 2000 (from 28.1 to 32.7 million hectares) as well as crops with stacked genes for herbicide tolerance and insect resistance (from 2.9 million hectares in 1999 to 3.2 million hectares in 2000), whereas the global area of insect resistant crops has decreased from 8.9 million hectares in 1999 to 8.2 million hectares in 2000. Globally in 2000, 16% of the 34 million hectares of cotton was transgenic, which was herbicide tolerant (2.1 million hectares), insect resistant (Bt)/herbicide tolerant (1.7 million hectares), and Bt cotton (1.5 million hectares).

Potential Benefits of GE Crops

A number of benefits are expected from the use of GE crops. These include: the decreased use of pesticides from modifying agronomic traits, and moderately higher yields from reduced crop losses. With respect to crops, due to expected lower pesticide use and constant or better yields, these GE crops should increase farmer's profits. They are also expected to decrease many of the environmental consequences of pesticide use through the use of less harmful active ingredients as well as overall reductions in active ingredients. This environmental externality of GE crops can provide important benefits to society as a whole. These benefits are given below for each type of GE crop.

Potential Benefits of Herbicide Tolerant GE Crops

Herbicide tolerance has been achieved through techniques other than genetic modification, for example mutagenesis. Modern biotechnology has been able to genetically modify a number of major agricultural crop varieties to resist/tolerate the application of wide-spectrum post-emergent herbicides, such as glyphosate based formulas. Genetic modification enables the insertion of genes which de-activate a herbicide when it is applied to the crop. Herbicide tolerance can also be achieved by inserting genes which replace an important enzyme in the crop which is susceptible to the herbicide applications.

GE cotton varieties resistant to Buctril herbicide, Glyphosate herbicide, called "Roundup Ready (RR)" and Sulfonylure herbicide became available in 1996 and 1997, respectively. It has been suggested that to obtain similar weed control results, Roundup Ready cotton requires lower herbicide use than the conventional treatments, though more than one application of Roundup herbicide is required. However, at present, it is not clear whether herbicide tolerant GE crops used in conjunction with a particular herbicide will lead to more or less herbicide use. A constancy in herbicide use rather than a reduction is possible.

The use of broad spectrum contact and systemic herbicides with herbicide tolerant GE crops may reduce the need for cultivation which encourages germination of weeds and to incorporate persistent soil acting herbicides into the soil. Mouldboard ploughing can have adverse effects on soil earthworm populations. Also reducing cultivation will help to conserve soil micro fauna and flora, and reduce soil erosion.

Broad spectrum herbicides such as glyphosate and glufosinate ammonium can be applied after weeds have emerged and remain active for relatively short periods of time. Herbicide tolerant GE crops allow the use of herbicides with a wider spectrum of activity which could be applied after the weeds emerge and which can be targeted at the correct growth stage to give the most effective control. Therefore, herbicide tolerant GE crops potentially offer greater flexibility and simpler programs of sprays.

Potential Benefits of Insect Resistant (Bt) GE Crops

Engineering plants with crystal protein genes from *Bacillus thuringiensis* (Bt), a soil bacterium, was one of the first projects in plant biotechnology (Peferoen, 1992). The use of Bt sprays had demonstrated their specificity and safety, the few Bt crystal proteins known at that time proved to be very active against certain important agronomic insect pests, the crystal proteins were encoded by single genes, and discovery programs indicated that Bt was an excellent source of proteins for new pesticidal activities (Payne and Sick, 1993; Grochulski et al., 1995).

Bt varieties of cotton were developed as alternative pest management strategies to control the principal cotton pests, cotton bollworm and the boll weevil. The transformed cotton with a Bt gene resistant to lepidopteran insects is called Bollgard™ in the USA and Ingard™ in Australia.

GE crops with insect resistance genes may reduce insecticide use by more accurately targeting the pests which attack the crop. However, the impacts on pesticide use depend on the degree of pest infestation in any given environment and year. A 1996 study of 300 growers in the Southeast United States found that pesticide applications were 70% lower, yields were 11% higher and profits attributed to Bt cotton adoption were about US$50 higher per acre (Marra et al., 1997). An econometric study based on ARMS data for cotton for 1997 finds that the increase in adoption of Bt cotton led to a significant decrease in insecticide use and significant increases in yield and variable profits (Fernandez-Cornejo and McBride, 2000).

It has been asserted that Bt crops themselves have minimal effects on non-target insects with which they may come into contact, and they may permit the establishment of beneficial insects in the field and field margins. Bt crops may have the potential to lead to more effective control of insects pests and may reduce the current dependence on agrochemical sprays, which may favor farmland wildlife. Consequently, GE insect resistant crops may provide an additional technique which could be a useful tool in an ICM system if specific research is carried out to identify how they may be integrated safely into such programs.

Potential Adverse Effects of GE Crops

It has been suggested that a number of potential adverse effects may arise from the release of GE crops into the environment. The likelihood of these effects occurring depends on the plant which was modified, the novel characteristics introduced by the genetic modification, and the way that the GE plant is used. GE crops may have potential adverse effects on the environment, human and animal health, as well as have potential impacts on agricultural practices and socio-economic structure. These potential adverse effects could include:

Potential Impact on the Environment

Most of the environmental concerns about GE crops derive from the possibility of gene flow to close relatives of transgenic plants, the possible undesirable effects of the exotic genes or traits (e.g., insect resistance or herbicide tolerance), and the possible effect on non-target organisms.

Potential Gene Transfer from GE Crops to other Plants

Transfer of the inserted genetic material to other crops or native plants, through pollination by wind or insects, could have adverse effects. For example, transfer of genes from herbicide tolerant GE crops to other related cultivated non-GE varieties or wild relatives via cross pollination may result in herbicide tolerant and multiple herbicide tolerant hybrids which may be difficulty controlled. Insect resistance genes may also be transferred to closely related plants which could gain a selective advantage over other native plants, because insect feeding, which is an important factor in restraining plant population growth, is reduced.

The potential for genetic escape from any one plant to another (whether non-GE or other GE crop plants or related wild plant species) depends on a cycle of events coming together:

- Dispersion of pollen containing modified genetic material by wind or insect;
- Simultaneous flowering of a recipient plant leading to successful fertilization;
- Production of viable seed;
- Germination, establishment and growth of fertile hybrid plant;
- Maturation to flowering of the hybrid (or recipient crop plant) and release of its pollen containing altered genetic material.

Relevant factors which will determine the likelihood of completing this sequence of events include: (1) the distance that pollen disperses compared with the isolation distances required for a GE crop and the extent of its separation from potential recipients, and (2) the geographical occurrence, proximity and flowering synchrony of wild relatives with the potential for fertile hybridization and the subsequent hybridization rates.

Potential Gene Transfer from GE Crops to other Microorganisms

There is a potential to transfer genetic material to soil microbes which degrade modified-plant material. The extent of any such gene transfer and its significance has to be assessed taking account the considerable varieties in the background status of soil microbes. Thus antibiotic resistance transfer may occur, but this needs to be related to the extent of pre-existing antibiotic resistance within the soil's microbial system. The fitness of the transformed species needs to be considered.

There is also concern about horizontal gene transfer that the existence of a transgenic plant with resistance for a particular pest or disease might exacerbate the emergence of new resistant pests or diseases.

Potential Dispersal of the GE Crop

Potential dispersal of the GE crop in the environment through possible increased persistence, invasiveness and competitiveness with native plant species could change the population dynamics of the release site and the surrounding environment. There is a potential for "gene-stacking" or the accumulation of different traits within the same plant when genetic transfer from other simultaneously flowering adjacent crops occurs or when there are residual flowering donor plants which have remained in the field from a previous crop (volunteer plants).

A crop plant which has acquired the capacity to express genes, e.g. conferring tolerance to two different herbicides, would require different methods of control from that needed when either gene is expressed singly in a crop plant. This dual incorporation of genes may have crop protection consequences in the field but the significance of any transfer of genes to a wild related plant will depend on whether any selection pressure occurs in non-cropped habitats. This selection pressure may provide an environment that confers a competitive advantage to the novel plant. On the other hand, unless managed carefully at the farm, the volunteer plants which emerge from previous year's herbicide tolerant GE crop, will be weed for the next crop of the agricultural rotation and these may be difficult to control.

Potential Adverse Effects on Non-Target Insects

Insect resistance genes in GE crops may cause adverse effects on non-target insects, if predators or parasitoids which feed on the pest are affected indirectly when feeding on prey or hosts which contain the toxin after feeding on the GE plant. This would depend on the specificity of the toxin encoded by the genetic modification, that is the number of other wildlife species which could be effected by the toxin.

Preliminary information is available from limited laboratory studies on the effects of consuming GE crop plants or their expressed gene products on non-target insects. For example, in relation to insect resistant crop plants (expressing a Bt toxin or a lectin), there is some information available from tritrophic studies involving target insect pests and their non-target predators or parasitoids. Insects may be exposed to pollen containing the expressed products of genetic modification which may be found on both GE and non-GE crop plants or the insects may themselves be pollinators collecting and storing materials. The impact on these insects or terrestrial ecology in general of changes in GE plants cannot be fully deduced from small plot trials.

Potential Impact on Biodiversity

The presence of a herbicide tolerant trait in a GE crop may result in a change in the pattern of herbicide use from that on the non-GE crop in terms of altered amounts or use at different times. This may affect on the biodiversity or structure of non-crop weed species in the field, which in turn may have an indirect impact on invertebrates associated with such weeds present in the crop.

In most situations, it is envisaged that a switch to GE herbicide tolerant crops will not necessarily increase herbicide use. It is likely that, in practice, the pattern of use of different herbicides will change. Fewer products may be used, and in reduced quantities. However, there are concerns that if each application of a broad spectrum herbicide is highly effective, the overall impact of herbicide use on farmland wildlife may be comparatively greater.

The insect pattern is also going to change due to cultivation of Bt crops. If one species of insects is suppressed strongly and continuously by Bt crops, some major insects will become minor pests, while some minor insects may become major ones. Also new insects may adopt to Bt crop more quickly due to less use of insecticides. Although effective control may be observed by Bt crops on one or more primary pests, all pests will not necessarily be controlled and chemical pesticides may still need to be applied. The need for two types of pest control methods may therefore increase the impact on non-target species and any perceived environmental benefits from the use of the GE crop may be lost.

Potential Impacts on Animal and Human Health

There are numerous potential concerns about consumption of GE crops, such concerns have focused on the potential for allergic reactions to food products, the possible introduction or increase in production of toxic compounds as a result of the GE technology, and the use of antibiotic resistance as markers in the transformation process (FAO and WHO, 1996).

Allergenicity

A food allergy is an adverse reaction to an otherwise harmless food or food component that involves the body's immune system in the production of antigen-specific Immunoglobin E (IgE) to specific substances in foods. Almost all food allergens are proteins, although the possibility exists that other food components may also act as haptens (FAO, 1995).

Assessment of allergenicity for GE products includes comparing the similarity of the transgenic protein with known allergens (i.e. whether the sequence homology is or is not the same as any known allergens). "Allergens homology" is clearly not a sufficient criterion to assess the allergic potential of a new protein and even less of a whole novel food derived from GE plants (Metcalfe et al., 1998).

Many of the genes now being considered for introduction to provide insect resistance depend for their action on disrupting the digestive function of the pest. It is therefore important to exclude the possibility that some of the enzyme inhibitors and lectins being considered may produce similar effects in mammals. In addition, if absorbed, these components could have effects on many aspects of metabolism, including the immune and hormonal systems (OECD, 2000 b).

Toxicity

Many crop plants contain natural toxins and allergens. The potential for human toxicity or allergenicity should be kept under scrutiny for any novel proteins produced in plants with the potential to become part of food or feed. Toxicants may be accumulated if the processes of introducing the transgenic material alter an existing metabolic pathway or introduce a new one both by gene technology and by modern conventional plant breeding (WHO, 1991).

Antibiotic Marker Genes

Marker genes are inserted into GE plants to facilitate identification of genetically modified cells or tissue during development. There are several categories of marker genes, including herbicide resistance genes and antibiotic resistance genes. Antibiotic resistance markers have been utilized during the transformation/selection process in the development of the vast majority of GE plants.

The concern has been raised that the wide spread use of such genes in plants could increase the antibiotic resistance of human pathogens (WHO, 1993). Kanamycin, one of the most commonly used resistance markers for plant transformation, is still used for the treatment of the following human infections; bone, respiratory tract, skin, soft-tissue, abdominal infections, complicated urinary tract infections, endocarditis, septicemia, and enterococcal infections.

Scientists now have the means to remove these marker genes before a GE crop plant is developed for commercial use. Developers should continue to move rapidly to remove all such markers from transgenic plants and to utilize alternative safe markers for the selection of new varieties. No definitive evidence exists that these antibiotic resistance genes cause harm to humans, but because of public concerns, all those involved in the development of transgenic plants should move quickly to eliminate these markers (OECD, 2000 a).

Substantial Equivalence

The concept of substantial equivalence is a useful framework to identify significant similarities and differences between GE foods and a suitable comparator that has a history of safe use (WHO, 1995). However, substantial equivalence does not give a clear idea about food or feed safety of GE products.

Long-term Nutritional Impact

The ability to modify substantially the composition of plants means that there are potential benefits as well as risks to the nutritional well-being of the population. When evaluating transgenic plants to be used for animal and/or human consumption to ensure that the nutritional quality of the crop is maintained or even enhanced rather than reduced during the practical procedures involving the selection of the most suitable transgene. If transgenic crops become an appreciable part of the diet then the long-term impact of nutritional changes in the amount, bio-availability or precise structure of any macro- or micro-nutrient could have a substantial impact on the health of the population. However, an evaluation of the long-term impact of these unpredictable changes on health and environment is poorly documented (European Commission, 2000).

Potential Impacts on Agricultural Practices and Socio-economic Structure

The constant exposure of insect pests to the expressed gene products when feeding on insect-resistant GE plants, may result in the more rapid development of resistance in target insect species compared with the use of discrete topical pesticide applications at infrequent intervals. Thus, with GE insect resistant crops, an earlier onset of failure to control the targeted insect pest may result. Target insects will develop resistance in five to seven years. Development of resistance could happen earlier, even in three years, if appropriate steps are not taken (Gould, 1995).

Resistance management options designed to delay or prevent the development of resistance include the siting of non-GE plants or "refuges" at sites adjacent to the Bt crops. This approach aims to provide nearby sources of susceptible insects to mate with so that the speed of developing resistance is decreased through genetic dilution. The refuges also provide local sources of natural parasites and predators (Andow, 1999).

The recommended levels of refuge use may be different for each species of GE insect resistant crop and its cultivating environment. For example, the following two types of refuges are recommended for cultivation of Bt cotton in the USA and Bt cotton growers must choose one of these options:

- For every 100 hectares of Bollgard cotton planted on the farm, 25 hectares of non-GE cotton varieties must be planted and treated with insecticide (except foliar Bt products).
- For every 100 hectares of Bollgard cotton planted on the farm, 4 hectares of non-GE cotton varieties must be planted and treated with any insecticide except those used for worm control.

In Australia, the following refuge options are recommended for Bt cotton cultivation:

- For every 100 hectares of Ingard cotton, a grower has to plant 10 hectares of irrigated non-Bt cotton which will not be treated with insecticides used to control *H. armigera*, or, for every 100 hectares Ingard cotton, plant 50 hectares of irrigated conventional cotton, which can be treated with insecticides to control *H. armigera* and *H. punctigera*.
- The refuge crop must be planted by November 15 close to Bt cotton. The refuge crop will be grown like a normal crop and will not be treated with Bt insecticides.
- Twenty hectares of irrigated sorghum or corn will be grown in every season and managed to flower between January 15 to February 28. Sorghum or corn will not be treated with products normally used to control worms (Fitt, 1996).

Genetically modified varieties are more costly than conventional varieties, due to a technology fee applied to the seed cost. These fees are based on the need for firms to recoup R&D investments in the development of the patented variety. Purchase of these varieties also carry specific requirements, fixed under contract, such as, no use or sale of own-grown seeds (for up to three years in certain cases) and a application of one of the refuge recommendations.

Economic models suggest that, under normal growing conditions and with a 10-15 year planning horizon, farmers capture most, if not all, of the benefits from Bt technology by planting a 20-30% refuge. At lower levels of refuge, the economic models are more sensitive to underlying biological and genetic uncertainties. Risk analysis shows that the cost to farmers of planting too much refuge is less than the cost of planting too little refuge (Sears and Schaafsma, 1999). Increasing a refuge from 10% to 20% is expected to decrease the value of Bt technology by less than 1%, while reducing the probability of resistance developing from 37% to less than 1%. On the other hand, reducing the refuge from 10 to 5% is expected to increase the probability of resistance development from 37 to 74%.

Large scale utilization of Bt genes is going to affect the economics of cotton production due to not only the cost of seeds (including technology fee) but also the cost of refuges. Adoption of Bt cotton seed purchased at a higher price will ensure the supply of pure seed and careful planting for better establishment. However, the cotton growers in developing countries will depend on importing of Bt, or in general GE, cotton seeds every year.

Risk Analysis: Risk Assessment, Risk Management and Risk Communication

The focus of debate on GE crops has been their safety in respect to food use and the consequences for the environment. Relatively little attention has been paid to broader questions of risk analysis. Risk analysis is recognized internationally as a process that facilitates fair and safe use and trade of GE crops and their products. It has been defined as a three-stage process, including risk assessment, risk management, and risk communication (Beringer, 2000).

Risk assessment is the procedure used to determine how safe a GE crop or food might be. Risk assessment demands that the people producing a Genetically Modified Organism (GEO), and those regulating the safety of its use, are aware of the possible harm that might arise from its use and how likely it is that the harm will arise. Risk assessment procedures should be carried out by independent scientists on case-by-case basis. Once the risks are understood, there is a need for individual countries to decide on the desirability of using the GEOs concerned.

In conducting risk assessment it is essential to remember that human safety is not the sole criterion. Often genes are cloned into organisms whose release might cause environmental harm. The potential harm is relatively simple to determine, but it is often less straightforward to assess the likelihood of the organisms accidentally entering the environment and infecting susceptible hosts. Even less straightforward, and sometimes neglected, is an assessment of the possibility that an accidentally-released GEO might cause environmental harm by displacing native organisms.

Risk management is the use of procedures for the identification, documentation, and implementation of the measures that can be applied to reduce the risks and their consequences. Risk management allows the handling of transgenes safely, even though their potential for harm might be very great. Risk management should always be incorporated into risk assessment, so that the GEO user is fully aware of the constraints.

Risk communication is the process for communication of the risk assessment results to the regulators of the import programs, and to other interested parties such as industry and public. Risk communication has to play a central role in ensuring that all stakeholders, i.e. the public, the industry and scientific community, are jointly aware and convinced of the care being taken with the assessment procedure.

Different approaches to risk analysis followed by countries have led to marked differences in market access, timing, and market share. Other countries of the world tend to be a part of either the U.S. or EU camp regarding current acceptance of modern biotechnology, although some have carved out intermediate positions. The U.S. and EU approaches show a different propensity to include what have come to be referred to as "other legitimate factors" in the risk analysis process. There is no definitive list of other factors but they may include economic interests, food security, animal welfare, environmental impacts, consumer acceptance, and other ethical concerns (Caswell, 2000).

Integrated Crop Management (ICM)

Enormous improvements in crop varieties, crop protection products, fertilizers and irrigation systems helped more than double world grain harvests in the last 40 years, but all agricultural activities had some level of environmental impacts. However, agriculture must be productive and sustainable, able to meet the needs of society and the consumer, without hindering the ability of future generations to produce enough food. Society requires not only sufficient, safe, and affordable food produced in an environmentally-friendly way, but agriculture must respect the natural resources of soil, water, energy and wildlife.

Integrated Crop Management (ICM) arose from the recognition of the need for sustainable and profitable agricultural production systems and concerns about environmental stewardship. ICM is a strategy which best meets the requirements of sustainable agriculture and sustainable development by managing crops profitably without damaging the environment or depleting natural resources for future generations. It is a dynamic system which uses the latest research, technology and experience in ways that suit local conditions to optimize food production, enhance energy conservation and minimize pollution world-wide.

Conclusion

Appropriate steps must be taken to meet the urgent need for sustainable practices in world agriculture if the demands of an expanding world population are to be met without destroying the environment or natural resource base. In particular, GE technology coupled with important developments in other areas should be used by carrying out all necessary risk analysis procedures to increase the production of main food staples, improve the efficiency of production, reduce the environmental impact of agriculture, and provide access to food for small-scale farmers. Consequently, if transgenic agriculture is applied taking into account all risk analysis procedures, it may be a new tool for Integrated Crop Management, otherwise it may be a serious threat for human/animal health and the environment.

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