INTRODUCTION OF TRANSGENIC CROPS AND THEIR POTENTIAL AS FUTURE WEEDS

Dale L. Shaner
American Cyanamid Company, PO Box 400, Princeton, NJ 08543, USA

Summary The use of transgenic crops has begun with the introduction of insect and herbicide resistant varieties. Transgenic crops will lead to new ways to manage pests, and reduce inputs, such as pesticides, fertilizer, and irrigation, while providing new products and more nutritional food. Will these same traits also increase the potential of the transformed crops to become new weeds? The likelihood a transgenic will become a weed will depend on how the introduced trait affects the ability of the transgenic to compete with native species. Each new transgenic must be evaluated individually in terms of the species, genetic modification, and biotic and abiotic factors in the environment into which it is introduced.

INTRODUCTION

The introduction of foreign genes into crops has been hailed by some as a great advancement in agriculture. It may result in the production of new foodstuffs, and industrial raw materials and allow us to tackle many crop production problems in a more sustainable fashion, while providing food for an increasingly greater world population. In contrast, others condemn the development of transgenic crops for fear that these new genes or transgenic varieties will escape into the natural population and wreak havoc (Hileman 1995).

Transgenic crop varieties have been and are being developed to increase crop tolerance to herbicides, insects, disease and environmental stress, as well as to change their nutritional composition and to produce industrial or pharmaceutical components (Dale *et al.* 1993). What effect will these traits have on the weediness of the transgenic crop? In this review, I will summarize the current state of the release of transgenic crops and their potential for becoming weeds. At present, there are no known cases where transgenic crops have become weeds.

DEFINITIONS

Transgenic crop A transgenic crop variety is one that contains a gene or genes from an unrelated organism (e.g. a bacterial gene in a plant) that could not be transferred to the crop using traditional plant breeding techniques.

Weed A weed is a plant out of place. Thus, any plant that is growing where it is not wanted is a weed. However, this definition is subjective, rather than absolute depending on the perspective from which it is perceived. What may be considered a plant out of place to one person, may be considered a wildflower to another.

CURRENT STATUS OF TRANSGENIC CROPS

Transgenic crop varieties containing many different traits exist in almost all of the major crops (Table 1). The first field tests of a transgenic plant was in 1986 in the United States and France. Since then there has been a rapid increase in the number of field trials of transgenics such that by 1992 there were 675 releases involving 31 different species (Ahl Goy *et al.* 1994). Of the major genes in the transgenics, approximately 33% were for virus and disease resistance, 28.5% for herbicide resistance, 28.5% for improved crop quality and 9.5% for insect resistance. The most extensive release of transgenic crop varieties have occurred in China, but the first major release of transgenics in the United States will be transgenic crops containing the *Bacillus thurigiensis* delta endotoxin or gene conferring insect resistance (Leidner 1994). In addition there is work being conducted to increase the tolerance of crops to environmental stress including extremes in temperature, water and salinity. There are over 60 private companies and 42 public institutions involved in developing transgenic crops (Ahl Goy *et al.* 1994), many trying to lower the use of crop inputs (pesticides, fertilizer, and irrigation) while maintaining yield and increasing the nutritional value of the crop.

POTENTIAL OF TRANSGENICS BECOMING WEEDS

There is uncertainty on how transferred traits might affect the weediness of the transgenic crop. Could these introduced traits increase the ability of the crop to invade natural environments or to become uncontrollable weeds under agronomic conditions? There are many examples where we have introduced plant species into a new environment as a crop only to have the species become a serious weed (Keeler *et al.* 1996). Could similar incidences occur with transgenics?

Before we can answer this question we must first determine the characteristics of a weed, and then determine if the traits introduced into transgenic crops have these characteristics. Baker (1974) proposed 13 characteristics of an ideal weed. These included:

1. germination requirement fulfilled in many environments,

2. internally controlled discontinuous germination,
3. long-lived seed,
4. rapid growth to flowering,
5. continuous seed production as long as growing conditions permit,
6. facultatively self-compatible,
7. if outcrossed, uses wind or unspecialized insects,
8. very high seed production possible,
9. some seed produced in many environments,
10. seeds adapted for short and long distance dispersal,
11. if perennial, vegetative growth or regeneration from fragments,
12. if perennial, hard to uproot, and
13. good competitor, forming rosettes, choking growth or allelochemicals.

The weediness of a plant is also influenced by the restraints placed on that plant such as herbivory, parasites, disease, and environmental tolerance. Successful biological control of introduced species such as tansy ragwort (*Senecio jacobea* L.) or St. John's wort (*Hypericum perforatum* L.) in California demonstrates that these foreign weed species were kept under control in their native habitat by these outside agents (Mitich 1994, Mitich 1995).

Keeler (1989) analysed a number of crops to determine which ones might develop into serious weeds through genetic engineering, by comparing the number of weedy traits crops possess to the number of traits in troublesome weeds. The crops only contained an average of five of these weedy characteristics while the weeds had 11 of them. She concluded that it was unlikely that transgenic crops would develop into serious weed problems because the transgenic trait would probably not change the crops enough to make them a problem.

The question then is what effect the traits introduced into transgenic plants have on the restraints limiting the spread of the normal crop variety. Introduction of insect or disease tolerance into a transgenic crop could release the crop from its normal restraints. However, most crops such as maize, cereals, rice, and cotton, are not major weed problems because their survival depends on intensive cultivation. Placing an insect or disease resistant gene in these crops probably will not greatly increase their potential as weeds. The trait could have an indirect impact if one of these traits were to escape into a weedy relative of the crop. In such a case, the weedy relative may become more invasive by the acquisition of the new trait.

The above analysis also applies to engineering plants for increased tolerance to environmental stress. Increasing a rice plant's saline tolerance through genetic engineering could allow it or its weedy relative, wild rice, to invade marshlands and displace native species. Likewise, a transgenic crop with increased tolerance to temperature extremes or to drought could allow feral populations to survive outside of their normal range, thus making them weeds.

Herbicide resistance has been the most widely engineered trait to be introduced into crops. However, in the absence of the herbicide, these crops do not appear to have any increased fitness over the normal cultivars or their wild relatives. Crawley *et al.* (1993) compared the invasiveness of two transgenic oilseed rape lines (kanamycin-tolerant and glufosinate-tolerant) with a conventional line. They found that the transgenic lines were no more invasive than the conventional line, and in those cases where there was a significant difference among the lines, the transgenics were less invasive.

Table 1. Examples of transgenic crops.

Crop	Transgenic trait[A]
Maize	Herbicide resistance (glyphosate, sethoxydim, glufosinate, sulfonylureas), insect resistance
Soybean	Glyphosate resistance, increased methionine
Tomato	Viral resistance, insect resistance, frost protection, glufosinate resistance, improved storage, flavour enhancer
Potato	Viral resistance, glufosinate resistance, increased starch content, production of serum albumin
Cucumber	Viral resistance
Cotton	Insect resistance, herbicide resistance (glyphosate, bromoxynil, 2,4-D)
Tobacco	Insect resistance, fungal disease resistance, cadmium tolerance, frost protection, cold tolerance, herbicide resistance (glufosinate, 2,4-D), increased mannitol
Oilseed rape, canola	Fungal disease resistance, herbicide resistance (glyphosate, sulfonylurea, glufosinate), increased stearic acid, increased methionine, increased lauric acid
Flax	Herbicide resistance (glyphosate, sulfonylurea)
Sugarbeet	Herbicide resistance (glyphosate, sulfonylurea, glufosinate)
Alfalfa	Glufosinate resistance

[A] Data adapted from Dale *et al.* 1993.

However, if the placement of herbicide resistant trait(s) into crops is not carefully considered, then we could have increased problems with controlling volunteer crops. Volunteer maize, for example, can decrease the yield of soybeans by 25% (Beckett and Stoller 1988). Before the advent of the post-emergent grass herbicides and the acetolactate-synthase-inhibiting herbicides, farmers either tolerated the yield loss or used hand weeding as the primary mechanism for control. Currently, these herbicides provide a simple and inexpensive means to control volunteer maize. This current ease of control could be jeopardized by the introduction of herbicide resistance traits into maize. Varieties of maize have been developed that are resistant to acetolactate synthase inhibitors, sethoxydim, glyphosate, and glufosinate (Duke 1996). There has been discussion by seed companies to incorporate these resistant traits into one variety to give the farmer more options for weed control and to simplify inventory control for the seed company. If a variety was resistant to all of these herbicides, the farmer would have few if any herbicides to control the volunteer maize in soybeans and would be forced to rely on mechanical means.

QUANTIFYING THE RISKS

Many of the traits that are being introduced into crops could potentially increase the weediness of that variety under the right circumstances. The next question to ask, then, is how much risk is there in introducing a transgenic crop into the environment?

The probability that a transgenic crop will develop into a new weed problem depends on the species, the genetic modification, and on biotic and abiotic factors in the environment into which it is introduced. (Tomiuk and Loeschecke 1993). Many attempts to quantify this risk have been made (Dale *et al.* 1993). Because of the limitations of the predictive value of our knowledge of ecology and ecological interactions (Dale *et al.* 1991), the risk is unquantifiable. With that, each new transgenic has to be evaluated separately. In addition, we lack information on the pollination system, interfertility relationships, and distribution of wild relatives of cultivated plants, which we need to make informed decisions about the risk of gene escapes from transgenics to wild populations (Darmency 1994).

There have been some attempts to quantify the potential risks of releasing transgenic crops. The SCOPE (Scientific Committee on Problems of the Environment) program was begun in 1982 to attempt to determine what properties of invading species contribute to their success as invaders and to identify the characteristics that make certain ecosystems more vulnerable to invasion than others (Mooney and Drake 1991). Data collected for this program showed that approximately five new species of higher plants successfully invade eastern Australia each year and that over 50% of the flora of New Zealand is composed of invaders (Mooney and Drake 1991).

Characteristics of species that are successful invaders are those with large distribution ranges, high intrinsic growth rates, and large founding populations. Communities that are most likely to be invaded are those with few species, absence of species with similar morphology to the invader, and a high degree of disturbance. Before introducing a transgenic crop, a detailed evaluation of the traits of the transgenic organism and of the properties of the environment into which they will be introduced must be completed. However, Mooney and Drake (1991) concluded that accurate predictions on the consequences of introduction of transgenics into the environment cannot be made.

In order to assess the potential of a transgenic crop becoming a new weed problem, one also needs to consider a host of factors based on the properties of the original parent line and on an assessment of how the transgenic trait may affect these properties. Tiedje *et al.,* (1989) summarized some of the factors that should be considered in the risk assessment. The attributes of the parent organism to be considered are:

1. its level of domestication,
2. ease of subsequent control,
3. origin,
4. habit, pest status,
5. survival under adverse conditions,
6. geographical range, and
7. prevalence of gene exchange in natural populations.

Factors to be considered in comparing the transgenic to its parent organism include:

1. the effect of the introduced trait on fitness,
2. use of resources,
3. environmental limits,
4. resistance to disease, parasitism, herbivory or predation,
5. the transgenics' susceptibility to control by chemical or mechanical means,
6. the level of expression of the trait, and
7. the similarity of the phenotype of the transgenic to the parent organism.

The chances are that most transgenics will not become supercompetitive because the parent crops are already highly modified and domesticated and transgenic traits often lower the fitness of the recipient. If the crop cannot persist without human help under local conditions, it is unlikely that the introduction of a transgenic trait will turn the new variety into a locally ecologically vigorous organism (Regal 1994).

MANAGEMENT OF TRANSGENICS TO PREVENT WEEDINESS

Steps can be taken to minimize the risk of a transgenic crop from either becoming a weed problem itself or from the gene transferring to a wild relative which could increases its weediness.

One of the critical steps occurs during the initial field testing of the transgenic. Regal (1994) recommended that these field tests should provide valuable information about seed dormancy, seed dispersal, fecundity, pollination requirements, growth, and germination responses to environmental stress and resistance to natural diseases, herbivory, parasites, and other natural restraints. With this information, the potential weediness of the transgenic can be assessed compared to the original parent line. Regal (1994) further proposes that the scientific strategy of the field plots should be to survey and list possible ways in which a transgenic may or may not cause problems on general release, and to use this list to define and focus on those aspects of the transgenic that require further information. Also, any new features of the transgenic that may have not been anticipated should be noted.

Keeler *et al.* (1996) proposed additional steps that could be taken to limit the ability of a transgenic crop from becoming a weed. These include:

Avoid engineering traits that have a high potential of increasing weediness into high risk crop-weed systems. In the United States, this includes eight crops. (oats, canola, artichoke, sunflower, lettuce, rice, radish and sorghum). These high risk crops are those which are grown in areas where wild relatives exist and there is a high potential of gene flow between the wild relative and the transgenic crop.

Develop compatibility barriers to prevent the movement of transgenes from a crop to wild relatives.

Develop genetic containment methods including suicide genes, interfertility barriers, and male sterility into transgenic lines.

Spatially isolate transgenic crops from wild relatives and other transgenic varieties. For most self-fertilized crops an isolation distance of 500 m is believed to be adequate. For outcrossing crops, this distance would have to be increased, although the exact distance will vary with the crop.

Use transgenics in an integrated system that utilizes multiple methods for pest and fertility management. A system that combines non-transgenics with transgenic crops will also mitigate the spread of the transgene outside of the farm.

Transgenic crops offer a new way to solve many agronomic problems and provide opportunities to produce new products. The risk of transgenics becoming new weeds appears to be very low. The probability of a transgenic becoming a weed will be determined by the ability of the transgenic to compete with native species, the density of the released plants and the habitat where they are introduced (Rogers and Parkes 1995). Proper management and monitoring of the introduction of transgenics into agriculture should prevent any major problem from developing. Each new transgenic crop needs to be evaluated separately in order to determine what risk is associated with its introduction. After introduction, each transgenic crop needs to be monitored to ensure that any unexpected problems will be discovered early on and necessary steps can be taken to correct them. In this way we can take advantage of the many benefits transgenic crops offer us while minimizing the risks involved in their use.

REFERENCES

Ahl Goy, P., Chasseray, E. and Duesing, J. (1994). Field trials of transgenic plants: an overview. *Agro-Food-Industry Hi-Tech* 2, 10-15.

Baker, H.G. (1974). The evolution of weeds. *Annual Review of Ecology and Systematics* 5, 1-24.

Beckett, T.H. and Stoller, E.H. (1988). Volunteer corn (*Zea mays*) interference in soybeans (*Glycine max*). *Weed Science* 36, 159-66.

Crawley, M.J., Hails, R.S., Rees, M., Kohn, D. and Buxton, J. (1993). Ecology of transgenic oilseed rape in natural habitats. *Nature* 363, 620-2.

Dale, P.J., Irwin, J.A and Scheffler, J.A. (1993). The experimental and commercial release of transgenic crop plants. *Plant Breeding* 111, 1-22.

Darmency, H. (1994). The impact of hybrids between genetically modified crop plants and their related species: introgression and weediness. *Molecular Ecology* 3, 37-40.

Duke, S.O. (1996). 'Herbicide-resistant crops: agricultural, environmental, economic, regulatory, and technical aspects', 420 p. (CRC Press Inc., Boca Raton).

Hileman, B. (1995). Views differ sharply over benefits, risks of agricultural biotechnology. *C&EN* 73, 8-17.

Keeler, K.H. (1989). Can genetically engineered crops become weeds? *Bio/Technology* 7, 1134-9.

Keeler, K.H., Turner, C.E. and Bolick, M.R. (1996). Movement of crop transgenes into wild plants. *In* 'Herbicide-resistant crops: agricultural, environmental, economic, regulatory, and technical aspects', ed. S.O. Duke, pp. 303-30. (CRC Press Inc., Boca Raton, FL).

Leidner, J. (1995). The revolution is here. *Progressive Farmer* September, pp. 22-4.

Mitich, L.W. (1994). Common St. John's wort. *Weed Technology* 8, 658-61.

Mitich, L.W. (1995). Tansy ragwort. *Weed Technology* 9, 402-4.

Mooney, H.A. and Drake, J.A. (1990). The release of genetically designed organisms in the environment: lessons from the study of the ecology of biological invasions. *In* 'Introduction of genetically modified organisms into the environment', eds. H.A. Mooney and G. Bernardi, pp. 117-29. (John Wiley and Sons Ltd. London, UK).

Regal, P.J. (1994). Scientific principles for ecologically based risk assessment of transgenic organisms. *Molecular Ecology* 3, 5-13.

Rogers, H. J. and Parkes, H.C. (1995). Transgenic plants and the environment. *Journal of Experimental Botany* 46, 467-88.

Tiedje, J.M., Colwell, R.K., Grossman, Y.L., Hodson, R.E., Lenski, R.E., Mack, R.N. and Regal, P.J. (1989). The planned introduction of genetically engineered organisms: ecological considerations and recommendations. *Ecology* 70, 298-315.

Tomiuk, J. and Loeschcke, V. (1993). Conditions for the establishment and persistence of populations of transgenic organisms. *In* 'Transgenic organisms', eds. K. Wohrmann and J. Tomiuk, pp. 117-33. (Birkhauser Verlag Basel, Switzerland).