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Horticultural Biotechnology: Challenges for Commercial Development

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THE ISSUES

Genetic approaches have been utilized extensively for crop improvement, and biotechnology has expanded the tools available to geneticists and breeders. Herbicide-tolerant and insect-resistant crop cultivars developed through recombinant DNA technology have been rapidly adopted for soybeans, cotton, maize, and canola. Between their first large-scale introduction in 1996 and 2003, the global area planted to transgenic field crops had grown to 67.7 million hectares, representing 55% of the area of soybeans, 21% of cotton, 16% of canola and 11% of maize (James, 2003). While 63% of this area was in the United States and 6% in Canada, 85% of the 7 million farmers growing transgenic crops were in China and South Africa. Although adoption is still limited in some countries, noticeably the European Union and Japan, other countries such as India, Brazil and the Philippines have recently approved the production of biotech crops. China, in particular, is supporting research on an array of biotech crops (Huang and Rozelle, 2004).

In contrast to the increasing global adoption of biotech field crops, biotechnology has had limited commercial success to date in horticultural crops, including fruits, vegetables, flowers and landscape plants. The first biotech crop to reach the fresh market was the ‘Flavr Savr’™ tomato having extended shelf-life (Fig. 1), and a processing version of this tomato had higher viscosity, allowing it to be made more economically into puree and paste (Fig. 2). Sweet corn, potato, squash and papaya varieties engineered to resist insects and viruses have

Figure 1. Calgene’s Flavr Savr tomato was sold under the MacGregor’s brand in the United States when first introduced in 1994. It was accompanied by information identifying it as being modified through genetic engineering to slow the rate of fruit softening during ripening. It was accepted by consumers, but was not a financial success due to problems in production and marketing. Photo by courtesy of Keith Redenbaugh.

Figure 2. Zeneca developed a processing tomato using similar technology to that for Flavr Savr. Blocking polygalacturonase activity slowed fruit softening and also resulted in higher viscosity, which allowed more economical processing into puree or paste. This product was successfully sold in the United Kingdom between 1996 and 2000. Photo by courtesy of Martina McGloughlin.

also been approved for commercial use and marketed, but papaya is the only horticultural crop for which transgenic cultivars have achieved a significant market share (about 70% of the Hawaiian crop shipped to the U.S. mainland is transgenic). Development of papaya cultivars resistant to the papaya ringspot virus has allowed the recovery of that industry in Hawaii after devastation from the disease in the early 1990s (Fig. 3; Gonsalves, 2004). Insect-resistant sweet corn and potatoes initially achieved sufficient utilization to demonstrate that they can dramatically reduce the use of pesticides in these crops, yet market resistance has largely prevented their widespread adoption, and the transgenic potato cultivars are no longer commercially available. Only limited amounts of insect-resistant sweet corn and virus-resistant squash are currently marketed in the United States, and with the exception of papaya and a few flowers engineered for novel color (Fig. 4; www.florigene.com), biotech fruit or ornamental crops are not produced commercially.

Various traits that would be desired by growers and consumers of horticultural crops, including novel genetic methods for disease and insect protection and weed control, longer-lived flowers and slower-growing grass, have been developed and tested without as yet achieving commercialization (Clark et al., 2004). What once was a significant pipeline of research and development in horticulture, as evidenced by the number of U.S. field trials of biotech horticultural crops, has recently dwindled to only a handful in fruits and vegetables (Fig. 5). Field trials of turf grasses (e.g., creeping bentgrass) and tree species (e.g., poplar) account for the majority of continuing field trials of ornamentals. As a consequence of the disappointing past commercial results and current market outlook, many horticultural seed and nursery companies are reducing their investments in research involving genetic engineering, although they are continuing to apply biotechnology to support traditional breeding activities, such as the use of DNA-based molecular markers.

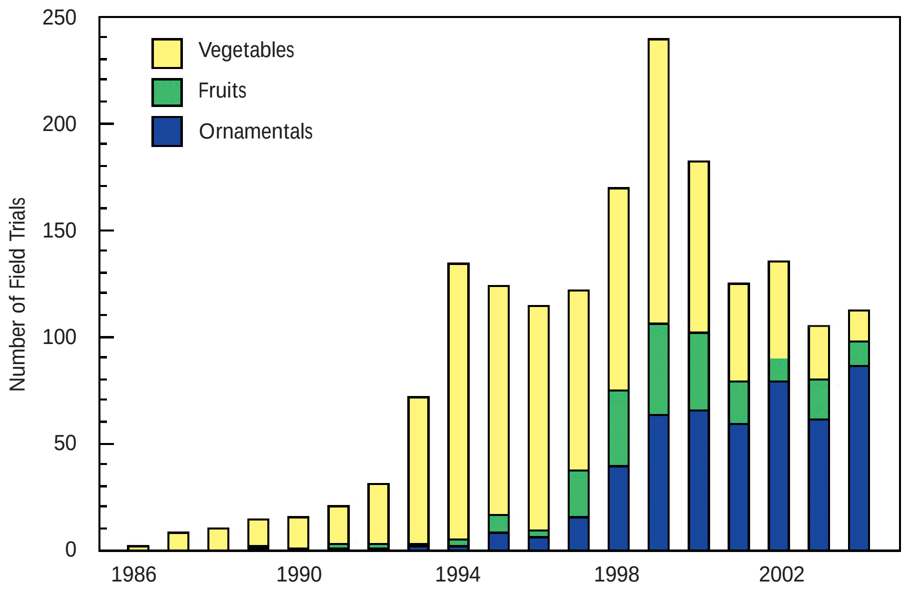
THE CHALLENGES

A number of technical, economic, regulatory and market factors have combined to create hurdles for the utilization of biotechnology in horticultural crops. Here we summarize the major challenges facing horticultural biotechnology (Bradford and Alston, 2004).

Figure 3. (Top) Papaya fruit infected with papaya ringspot virus shows the small darkened rings that make it unmarketable; the virus also causes foliar damage. (Bottom) 'SunUp' cultivar of papaya resistant to papaya ringspot virus was developed using biotechnology. Photos by courtesy of Dennis Gonsalves.

Figure 4. Florigene, of Melbourne, Australia, markets transgenic Moon™ series carnations engineered for blue-violet color. Photo by courtesy of Florigene.

Figure 5. Field trials of biotech vegetables, fruits and ornamentals conducted under permits in the United States, 1986 to 2004. Data for vegetables do not include potatoes or sweet corn. Data for ornamentals includes tree species. Data source: U.S. Department of Agriculture Information Systems for Biotechnology (http://www.nbiap.vt.edu/cfdocs/fieldtests1.cfm).



Species Diversity

Hundreds of species and thousands of cultivars are represented among fruit, vegetable and ornamental crops. In most cases, specific procedures are required for transformation of each species, and often even cultivars differ widely in the ease with which they can be transformed. Thus, introducing a trait into a specific crop and cultivar may require considerable research and development before it is even feasible. The diversity of propagation and marketing mechanisms also presents challenges, as many horticultural crops are vegetatively propagated from cuttings or grafting, rather than by seed, and are perennial, bringing different issues for containment and post-commercialization stewardship.

Multiple Niche Markets

Horticultural markets are highly segmented into a multitude of niches by location, season, consumer preferences, and other factors. Satisfying these diverse markets requires many cultivars within each species that may vary for resistance to pests and diseases, dates of maturity, seasonal adaptation, color, shape, taste and other attributes. Thus, introducing a particular trait into a horticultural species likely requires its introduction into multiple cultivars to achieve market success. Since regulatory approvals are based on individual transgenic events, this generally necessitates extensive backcross programs using a single initial transformed line, which can result in transfer of undesirable traits and delay forward breeding programs. In many perennial or vegetatively propagated species, backcrossing is not a viable option.

Small Production/Market Windows per Cultivar

Multiple niche markets for horticultural crops also mean that any single cultivar is likely to be successful only for a relatively small fraction of the total market for that crop. The potential crop area (and sales) of a given cultivar is therefore limited, and the potential returns on a biotech trait solely from seed or propagation materials may be too small to justify the investment. This is particularly the case with the current regulatory requirements that significantly increase development costs relative to conventional cultivars (Redenbaugh and McHughen, 2004). Mechanisms for cost recovery and value capture for perennial crops have also not been established, since the value of a novel biotech trait extends over many years after the initial sale of propagative materials.

Requirements of Processors

Some biotech traits would be highly beneficial for processors, such as high viscosity in tomato or insect resistance in sweet corn. However, processors often have recognizable brand names that are much more valuable than any single product. There is little incentive for them to jeopardize their overall market position by risking protests from anti-biotech activists over the introduction of a single biotech product. In addition, many processed products are marketed internationally, so that regulatory approval would be required in each importing country, possibly with each having different testing or labeling requirements. Segregating or channeling processed products for different markets is possible, but would require extensive (and expensive) changes in current production and distribution systems.

Requirements of Distributors and Retailers

Distribution and retailing of horticultural products is increasingly global and concentrated. Only 30 firms are estimated to account for 10% of global grocery sales, and 30% of Walmart's $259 billion in global 2003 sales were in groceries (Cook, 2004). Large distribution firms can dictate standards independently of any regulatory system, so whether they agree to market a particular product can spell the difference between success and failure. The major issues for marketers are labeling, traceability, liability, and global markets. Many countries require labeling if recombinant DNA techniques were used in producing a food product, but standards vary, particularly for processed or mixed products. Harmonizing such requirements would reduce uncertainty in marketing, but achieving international agreement on these issues will be difficult. Traceability is the ability to track a product from the market back to the field or greenhouse where it was produced. While this is possible and a standard practice with whole flowers, fruits and vegetables in some markets, it becomes much more difficult with products that are commingled during processing. Segregation of products is possible, such as is done for organic products, but requires higher prices. Liability is a critical issue, as demonstrated by the product recalls that occurred following the 'Starlink'™ maize situation in the United States. Without reasonable thresholds for adventitious presence of biotech DNA or protein, the risk is high with little or no benefit to the distributor. Again, this is exacerbated by global marketing, where differing thresholds or regulatory approvals could make a product legal in one country but not in the next.

Benefits to Growers, Processors, Distributors and Consumers

While the first wave of biotech products were targeted primarily to growers, benefits throughout the marketing chain will be needed to ensure adoption. Products having clear benefits to the consumer may be needed first to develop demand that will pull them through the marketing chain. These will likely require a premium price to compensate for the additional tracking and segregation that may be needed to ensure that the promised quality is delivered. They will also require consumer education to better understand how biotechnology fits into food production systems (James, 2004). If horticultural biotechnology is to move beyond the initial phase of input traits into output and consumer traits, attention must be paid to the interests, concerns and requirements of all participants in the production, processing, distribution and marketing chain.

Public versus Private Research

Public institutions have traditionally played a major research role in horticultural crops, and this is also true of horticultural biotechnology. How should they respond to the declining private interest in biotechnology research? It may be appropriate to increase support for public horticultural biotechnology research in some cases where there is a compelling public interest. This may be the case, for example, where a devastating disease threatens a horticultural industry and a biotech-based solution is the most viable option for developing resistant cultivars. Another example might be the development of nutritionally enhanced food products. However, public institutions generally do not have access to the full range of enabling technologies and trait genes, nor the resources to satisfy the regulatory and stewardship requirements that are needed to develop a commercial biotech cultivar, making public-private partnerships an attractive avenue for development (Rausser and Ameden, 2004).

Access to Intellectual Property and Enabling Technologies

A limited number of large corporations have acquired or licensed the enabling technologies and traits needed to develop and market a biotech cultivar. In some cases, they may not be willing to license these technologies for use in specialty crops, or the costs of licensing patented technologies from diverse sources may be too great to be economical for a small market crop. New licensing structures for enabling technologies developed in universities and public research institutions may be particularly helpful for small-revenue crops (as well as for developing country applications) (Graff et al., 2004). The Public Intellectual Property Resource for Agriculture (PIPRA) recently established at the University of California, Davis, with funding from the Rockefeller Foundation represents a significant development in this area (www.pipra.org). Public research agendas can also be targeted toward developing new methods that can lower intellectual property and regulatory barriers and thus enable horticultural crops to have access to modern biotechnologies.

Regulatory Requirements

Regulation and monitoring are needed to ensure that novel traits are assessed for food and environmental safety prior to commercialization. However, such prudent precautions should not be so restrictive as to present insurmountable barriers to the commercialization of horticultural products that could provide significant benefits to producers and consumers as well as to the environment. Current regulations that consider cultivars developed using recombinant DNA as a distinct category from those developed using other genetic technologies, including wide crosses, protoplast fusion or mutagenesis, markedly increase the costs of development and testing (Redenbaugh and McHughen, 2004). As noted above, the diversity of regulations and regulatory bodies is particularly burdensome for commodities traded internationally, as most horticultural products are.

RESEARCH AGENDAS

The intelligent application of biotechnology is compatible with and has much to contribute to agricultural and environmental sustainability while bringing value to producers, distributors and consumers. However, commercialization of such applications has been largely stymied to date, and additional research in both scientific and policy arenas is needed to expand opportunities for horticultural biotechnology. With that view in mind, we have summarized some of the key research and policy objectives for horticultural biotechnology.

Research Objectives

New Technologies and Products

- Develop efficient transformation technologies for many specialty crops
- Develop promoters for tissue-, development-, disease- and environment-specific gene expression
- Develop targeted gene-insertion techniques to control the site of integration
- Develop a Generally Recognized As Safe (GRAS) set of methodologies that would not require characterization and registration of individual genetic insertion “events”
- Develop products having clear and significant benefits for consumers

Regulatory Process

- Develop methods to quantify potential risks associated with individual species/trait combinations
- Test product safety, potential for gene transfer to non-crop organisms, and the biological and environmental consequences of any such transfers
- Develop quantitative evidence on the total benefits and risks of biotech versus conventional technologies, including human and environmental health
- Quantify full economic costs of different regulatory policies

Marketing and Adoption

- Model and measure the determinants of consumer demand for biotech foods and how consumer attitudes change over time
- Model and measure the determinants of producer adoption of biotech products
- Model and measure the roles of food processors and marketers in affecting farmer adoption and market acceptance of biotech products

Policy Objectives

New Technologies and Products

- Develop a collaborative public-technology and intellectual-property resource
- Develop technology and trait licensing packages to enable public and entrepreneurial commercialization of minor and subsistence crops
- Target increased public research funding toward application of genomics and biotechnology in horticultural crops, including methods that support traditional breeding

Regulatory Process

- Examine current regulations in light of accumulated experience and reduce redundant regulatory requirements when appropriate and justified
- Establish risk analysis protocols that treat biotech and conventional technologies on a comparable basis
- Replace regulation based on a single gene-insertion “event” with a more general approval of species/trait combinations
- Create or extend governmental programs to assist small-market crops in data collection required for the regulatory process

Marketing and Adoption

- Establish identity-preservation and channeling programs to allow co-existence of diverse market segments
- Establish practical thresholds for adventitious presence of approved biotech products to facilitate international trade
- Provide documented scientific information on the relative risks and benefits of biotechnology for horticultural crops

FUTURE PROSPECTS

Even as the adoption of biotech field crops increases every year, biotech horticultural products are struggling to emerge into the marketplace. There is no shortage of targets and applications, particularly with respect to pest management, where biotech crops could dramatically reduce the high rates of pesticide use in horticulture (Gianessi, 2004). However, it appears unlikely that additional biotech traits providing primarily grower benefits (so-called input traits) will be marketed in the near future for most horticultural crops (herbicide-tolerant turf grasses may be an exception). The processor and distributor segments of the supply chain are unwilling to risk even slight consumer rejection, regardless of the benefits to growers. Possible exceptions to this could be situations like that with papaya in Hawaii, where a disease or pest is so devastating that the entire industry is threatened and the only available solution is a biotech approach. Nutritionally improved horticultural products could appeal to consumers and create demand that would lessen distributor risks. However, most targets for nutritional improvement require metabolic engineering of multiple genes, which will need additional research to achieve. Testing requirements to obtain regulatory approval for nutritionally enhanced products will likely also be higher than for current products that are substantially equivalent to their conventional counterparts with respect to composition. Until such consumer-oriented products are available to open the markets to biotech, tangible benefits for growers and for the environment from input traits are not likely to be realized.

Counterbalancing this grim picture for horticultural biotechnology are some positive developments. Fundamental scientific advances continue to occur at a rapid pace, and the genomes of horticultural crops are beginning to be sequenced. Researchers and breeders in horticultural crops will increasingly be able to access and apply the information being developed in the more intensively studied model plants like *Arabidopsis*, rice and maize. Public institutions and foundations are collaborating through PIPRA and other organizations to lower the intellectual property barriers for international agriculture and specialty crops (Delmer et al., 2003). The continuing adoption of biotech field crops is stimulating the establishment of regulatory and biosafety protocols around the world, and the European Union is slowly beginning to relax its moratorium on approvals of biotech crops. China's significant investments in horticultural biotechnology, along with their huge internal market, will allow continued scientific and commercial progress in that country (Huang and Rozelle, 2004). Nutritionally enhanced "foods for health," such as canola and soybean oils with enhanced content of omega-3 fatty acids (Ursin, 2003), are being developed, and if accepted by consumers, could open the door for acceptance of similar products in horticultural commodities. A few ornamental biotech products are in the market, and additional ones may face lower hurdles for acceptance since they are not consumed. Thus, while the timeline for a significant impact of biotechnology on horticulture will be pushed back from earlier predictions, continued research is creating products that will eventually lead to acceptance by growers, processors, distributors and consumers.

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