Opportunities and Challenges for Specialty Crops: Will They Sell If Developed?

Roger N. Beachy
Global Institute for Food Security
Saskatoon, Saskatchewan

rnbeachy@danforthcenter.org

With this presentation, my role is to help to stir the discussion. Perhaps it will open the dialogue so that we have a sense of where we have been, where we are, and then what's ahead. Figure 1 shows a photograph from 1986, and in Figure 2 is a photograph taken two years later. We developed a tomato phenotype—viral coat-protein-mediated resistance to a common disease of tomato—with a technology that we hoped would be applicable to other horticultural and agricultural crops.

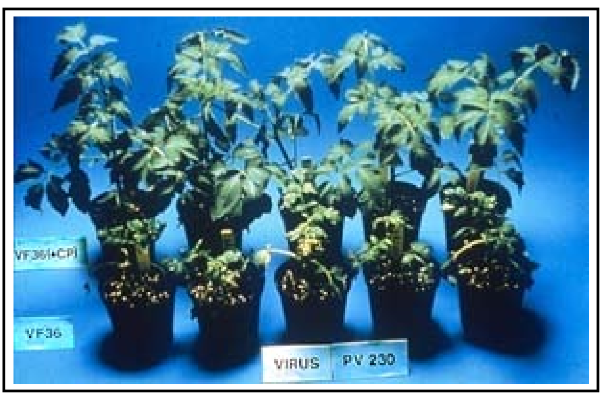

Figure 1. 1985: Coat-protein-mediated resistance to virus infection in tomato.

Since the field trial, fewer than six public-sector transgenic crops have reached the market in the United States. For the last 15 or 18 years, we've asked why it's been that way and if the situation will improve in the near future. If it does get better, what steps will be required to get there. I will discuss this in the context of reduction of the use of

Figure 2. 1987: First field trial of genetically modified tomato plants similar to those described in Figure 1, conducted in Jerseyville, Illinois.

pesticides and improved sustainability, and the role that this and other sciences play in the economy.

Increasingly, the topic of this conference, biotechnology and horticultural crops, is about the ability of producers to make a profit, and how future agriculture, globally, will include specialty crops. Although we cannot accurately predict the future of technical successes or consumer acceptance of new crop varieties, we should be planning ahead, as it can take 10 or more years to bring a new technology to the market. We should be looking ahead at what the economic picture may be—knowing what farming is like today, knowing what smallholders in Africa might want, or what might be useful in the prairies of western Canada, in Florida and other regions of the world.

I want to consider the technical opportunities and market challenges and possible solutions in the biotechnology of specialty crops, and then look for trends and goals that may portend a brighter future. We know where we've been. The technologies that were developed in the 1980s in transgenesis provided good products that brought value to producers and, arguably, to consumers by keeping food available at reasonable cost; also, they brought environmental benefits.

However, progress in applying the new technologies to specialty crops has been limited. The stumbling blocks are not technical, but regulatory and social. The challenges are magnified by the fact that the crops are of relatively small acreage and that consumer concerns over genetically modified (GM) crops are not waning. Activists are becoming more vocal, and we don't seem to have a plan for mitigation of damage that they cause to the effort to develop useful varieties through biotechnology. Nevertheless, public-sector scientists have continued their investment in the technology as it fits their research goals, and they continue to create products that are likely to have value, should they be adopted. As a plant pathologist, it is heartening to see the progress that has been made by researchers in the public sector, for example improving resistance to fungi, bacteria, insects and parasites, including parasitic nematodes, in specialty crops. Virus-resistant traits have been introduced in many specialty crops.

Biotechnology has also been employed to enhance nutrient content in tomato, rice, maize and other crops. Good examples are the purple tomato with high levels of carotenoids, increased tolerance of disease and strong post-harvest stability, vitamin-C-rich carrot, and potato varieties resistant to early blight and to late blight. A large number of virus-resistant crops have been developed by researchers abroad, showing how science and biotechnology have proven to be valuable. The question is, Will the full potential for application to specialty crops be realized? Given all of the good work that has been done, what's stopping it? Why isn't it moving forward? It is not a technical problem. Clearly, other issues need to be addressed.

A Long-Term View is Necessary

Let's look at today's problems in the context of what the long-term future might bring in agriculture, and ask several questions for US agriculture:

- Who is defining the long-term future of US agriculture in competition with BRIC[1] nations and other emerging economies, and how will decisions in technology and markets impact the future?
  - What will be the impact on US agriculture of increased productivity of commodity crops in Eastern Europe and South America?
  - Over what timeframe will changes occur?
- In the context of: increasing focus on health and nutrition, how will technology in horticultural crops be judged? How will value added to agricultural products be captured and will it change? What will be the impact of ongoing changes, both positive and negative, on farm economies in an era of high land values? And how will land values' impact on the roles of specialty versus commodity crops in the US economy change?
- What will be the markets for US agriculture exports when African nations become food self-sufficient in 20 or 25 years (as some have predicted), and when/if Eastern Europe produces more wheat and corn for European markets, and when Brazil fully exploits the Cerrado[2] for production of increasing amounts of soybean and corn?

If you ask who is in charge of outlining a plan for America's agricultural future, you may not find a long-term plan, though a mid-term roadmap was developed by the USDA in 2012. A useful roadmap should identify and address the challenges to the future of America's agriculture. Are increases in yields possible in commodity agriculture and what is required to achieve yield goals? What will impact the future profitability of specialty crops and how will challenges be managed? At the end of the day, a major issue is whether

[1]Brazil, Russia, India and China.

[2]A vast tropical savanna, the largest of Brazil's major habitat types after Amazonia.

or not the farmer/producer can make a living, whether (s)he can still pay the mortgage on the land and purchase the equipment that will affect profitability, and contribute to the wellbeing of the family. A useful roadmap will plan forward to provide a basis for ongoing success in the industry.

In a recent publication—Agricultural Innovation: The United States in a Changing Global Reality—Philip Pardey and Jason Beddow (2013) enumerated future challenges to agricultural economics that can be useful. We in the sciences and business sector, focused as we are on our own projects and products, often forget the bigger picture, to our detriment. To capture new value from agricultural products, there's an increasing awareness of the potential value of a growing bioeconomy and of biorefineries. Similarly, the growing role of consumer preferences and demands for agro-sustainability will continue to change agriculture. For example, I am convinced that biotechnology can reduce the use of agrichemicals on fruits and vegetables, improve quality and yields, reduce post-harvest losses, enhance climate resilience, and increase nutrient value and economic returns. If I am correct, investments made in research that helps to achieve these goals will prove to be warranted. The risk is that I am incorrect and that consumers will not push to reduce agrichemicals. To increase the likelihood that sound research goals are set, it will be helpful to engage the broad range of skills from the social sciences—including economics, consumer studies and policymaking—in the goal-setting process.

The Right Technologies at the Right Time

Recent advances in the science and technology of molecular plant breeding make it possible to consider the future of applications of biotechnology to horticultural and specialty crops that may be brought forward, for example new energy crops and those that produce biopolymers for the rubber and plastics industries. Quality of product and quantity of production can now be advanced rapidly by modern breeding and used to improve resilience to climate change and extreme weather, and to increase fertilizer-use efficiency. Furthermore, previously unexploited specialty crops may be employed for new industrial uses by applications of synthetic biology to alter metabolism and create useful products. Tools available today are far more powerful and useful than what we used, or imagined, in 1985 when we developed the first virus-resistant tomato plants. New tools include:

- High-frequency mutagenesis to create variability and select desired changes in target gene(s)
- Directed nucleotide changes in target genes to recapitulate known/desired variations
- Site-specific gene insertion
- Artificial chromosomes to carry multiple genes
- Deletion/inactivation of non-desired gene(s) via meganucleases
- Non-transgenic progeny via segregation in breeding
- Gene inactivation by RNAi-based approaches, including directed methylation and knockout.

We can expect continued technical improvements of course, and some of the new technologies will push the relevant regulatory processes to consider advantages of enabling technologies as well as the products to which they lead. The objective of the new technologies is not to circumvent regulatory oversight, but to develop new materials that will have increased value for those who take them to the marketplace and to the consumers who will use them.

Opportunities as Patents Expire

New opportunities for development will come through the expiration of patents and will lead the way to generic products, or will release constraints on commercial development of new products. Although patent protection for Agrobacterium-mediated transformation of plants will not expire until the late 2020s, products that made use of the technology will become generic much sooner. For example, the coat-protein gene-based virus-resistance patent was issued (17 years after filing) in 2003, and will be generic by 2020.

Certain technologies for Roundup resistance, and for insect resistance will likewise expire in the early 2020s and lead to new opportunities for new applications.

Challenges and Threats

The key challenges to development of biotechnology products in specialty and horticultural crops remain around the cost of regulation of traits and in accessing technologies resulting from industry investments in first-generation GM crops. We look forward to having not only resistances to disease and insects that were developed in first-generation crops, but also we look forward to herbicide tolerance and other traits that will come off-patent in the next 5 to 10 years.

Many relevant and valuable traits have been demonstrated in specialty crops, but few have been introduced in the marketplace. As others have reported, the significant cost of deregulating a biotechnology product compared with the value of the trait per se is a real and ongoing problem, especially in those cases when a disease or insect pest affects a relatively small geographical area.

In other cases, there is lack of scientific and technical information to bring to bear on a problem. A significant challenge in North America—as relevant in Canada as in the United States—is reduced investment in discovery research. We all ought to be concerned about this. Pardey and Beddow (2013) noted that increases in investment in agricultural science in the BRIC nations is directly related to increases in their crop productivity. In contrast, in North America there is flattened or reduced investment in research in agriculture-related sciences in inflation-adjusted terms; we are not keeping up with our competitors, although we have built successful agriculture economies on such competition. In 2012, the United States exported nearly $140 billion worth of agricultural products. Yet, in the United States, the Department of Agriculture invests less than $2.5 billion dollars annually in research, and less than $350 million dollars is available for competitive research grants. That level of investment is catching up with us, begging the question of agricultural profitability in the continent in 20 to 50 years. The negative impact of less discovery research could be substantial.

The weak history of innovation and entrepreneurship in our public institutions, upon which to build new enterprises and refresh established products, has led to a weak pipeline of new technologies. I participate as an advisor on several venture-capital funds and the paucity of innovation has, to date, been noticeable and is significantly less dynamic than from the biomedical community, and far less than for the IT sector.

It's not that the science itself is not outstanding. It is common to hear venture-fund managers reflect on the lack of innovation in this market sector and to relate it to the fact that the way to market for products improved by certain genetic technologies is unclear. The weak pipeline of new technologies, and the heavy and high-cost regulatory process in the United States and globally causes delays in release of new products. This is confounded by the lack of harmonized and synchronous approval processes that have together slowed product approval, which, in turn, has slowed innovation. This is further exacerbated by the weak acceptance of new products by a very vocal minority of consumers—in particular products developed by multinational corporations—which affects all of us.

These are some of the significant threats and challenges that affect the applications of biotechnology to horticultural and specialty corps. On the upside, the USDA process has improved modestly. There are additional requirements, but maybe we should have predicted some of the changes, for example the growing need for studies of environmental impact of new products, as unscientific as it may seem in some cases. Maybe we should have expected the changes. EPA and the NEPA[3] rules continue to represent substantial barriers to the release of new products.

The global approval process—which negatively impacts release of new products here in the United States—continues to be slowed by a variety of factors. And then there are events like the GM wheat that appeared recently in Oregon, and you wonder how long that tale will last, and how it will be used and by which group. Careful investigation is needed to elucidate how that happened in order to prevent recurrence, whether by accident or by intention.

Consumer concerns around GM crops are no lower than they were a decade ago, and are growing in some regions, as indicated by the labeling initiatives that we see in as many as 20 states. The same issues apply in Canada and in countries around the globe: we as scientists have a lot of work ahead as we take a more active role in discussions about GM foods.

Deregulation of Proven Technologies

Many scientists, though not all, are convinced that some of the controversies around GM food would diminish (1) if the benefits of GM varieties were more apparent to the consumer, and (2) if regulatory hurdles were reduced to levels commensurate with risk. It would help if agencies would deregulate based on past experience with a technology, and based on scientific evidence of no or minimum risk. At the same time, this would demonstrate to the public that—while the regulators are watching carefully—this is not

[3]National Environmental Policy Act.

a dangerous technology. We have boxed ourselves *in vis-à-vis* consumers by saying that the technology needs lots of regulation, when, in fact, most in the science community recognizes that it does not. Many feel that it is logical to deregulate *Agrobacterium*-mediated transformation, at least some Bt genes, and genes that confer resistance to herbicides proven to be effective and safe for the environment. Similarly, pathogen-derived resistance to viruses should be deregulated. Also, I would include all RNAi approaches to control pathogens, in particular when siRNAs are shown to be part of an innate defense mechanism. However, I am not optimistic that this will happen in the near future. But, since we have 20 to 25 years of success with some technologies, we ought to be pushing APHIS and EPA to deregulate certain technologies more actively than we are. And if APHIS is, as they claim, a science-based regulatory agency, we should expect to receive informed responses. This may be a way that we in the academic community could help to move beyond the current slow-and-go regulatory process and move new products to market more rapidly than they are today.

Perception of Multinational Companies

I am convinced that many of the challenges that we in the public sector face in our difficulties in GM agriculture are because many of us in university research are not seen as relevant to local agriculture *per se*. It is not easy for consumers of food to connect with our laboratory research. Instead, they generally see agriculture and the food economy as connected to large agribusiness and multinational food companies, which, they are convinced, do not have consumers' interests at heart. Although we know that not to be the case, we academics are either not seen as relevant or are painted with the same brush.

For some time, I have had a sense that this issue has arisen because our universities are now less involved in product development than historically. One way to minimize the latter may be for regulatory agencies to deregulate essential technologies that are broadly applicable, so that we can use them to address local problems. Horticultural and specialty crops are regional in their relevance. In the mid-1990s, Benigno Villalón who developed thousands of varieties of hot chili peppers in Texas, sent a postdoc to my lab to develop coat-protein resistance to viruses, which commonly infect chili peppers. However, he withdrew the effort on realizing what would be involved in achieving deregulation. Similarly, there is much innate interest in using genetic engineering to tackle local pest and disease problems in many crops.

Achieving Deregulation

New technologies are developed in public research institutions as well as in small and large privately held companies. The deregulation process as it currently stands is poorly defined and costly. Achieving deregulation of virus-resistant papaya, led by Dennis Gonsalves[4] of the USDA in Hawaii is estimated to have cost less than $1 million. In Brazil, a new virus-resistant *Phaseolus* bean cost $3.5 million from the start of the project to product

[4]Pages 37–46.

delivery. On the other hand, putting a new trait into a globally important crop—maize, soybean or cotton—is expensive, estimated to be between $50 million and $150 million, depending upon what is required. This discourages innovation, and it certainly discourages venture capitalists from investing in projects to which they cannot predict an end-point. In some ways we don't have a discovery problem in certain technologies, but we do have an innovation and translation problem. Policymakers are reluctant to develop long-term policies for the agriculture/food sector, including regulatory policies for new technologies.

An additional problem is limited understanding of how to achieve customer acceptance of biotechnology, due to concerns over food and environmental safety and intellectual property rights. The past 20 years haven't worked well for us, yet we have little concept of what we should be doing. A better way forward is not likely to come from multinational companies due to lack of trust on the part of consumers. But unless we face this impasse and find a better way, in 10 years we will still be asking ourselves, "Why isn't there more acceptance of crops developed with new genetic technologies?"

Messaging Agbiotech for Public Consumption

In 2011, Graham Brookes and Peter Barfoot published a paper titled *GM Crops: Global Socio-Economic and Environmental Impacts 1996–2009*, which focused on positive economic impacts, and production and environmental effects of GM crops. Within a week of the publication of Brookes and Barfoot (2011), Vandana Shiva and colleagues (2011) published *The GMO Emperor Has No Clothes: A Global Citizens [sic] Report on the State of GMOs—False Promises, Failed Technologies* (Figure 3). Certainly this was no coincidence.

At an NABC conference some years ago, I remember standing and asking her, following her remarks to the attendees, "Do you really teach this to your students? Do you call yourself a scientist? Do you really believe what you are saying?" My questions didn't matter, of course. Vandana Shiva has been saying the same things, making the same accusations, for the last 15 years, and because this is the kind of "stuff" that garners publicity, the issue won't go away. The private sector has yet to learn how to message agriculture and biotechnology for public consumption and how to address those who attack their work unrelentingly.

What might be done to counter? In my opinion, we should encourage transparency at all stages of the process—from research to testing, to product development and regulatory approval. Perhaps we should "open all the books"; perhaps that would help. And, there should be more public-sector voices in support of science and technologies in food and agriculture. And, in terms of transparency in our work, we need to demonstrate that we are, in fact, looking at real advantages, real sustainability, with real reductions in the use of agrochemicals, and other important outcomes for the research that we are engaged in.

Meeting Global Food Security.

What we do in specialty crops is part of the challenge of meeting global food and nutrition security. According to the FAO, we must feed another 2 billion people with sufficient

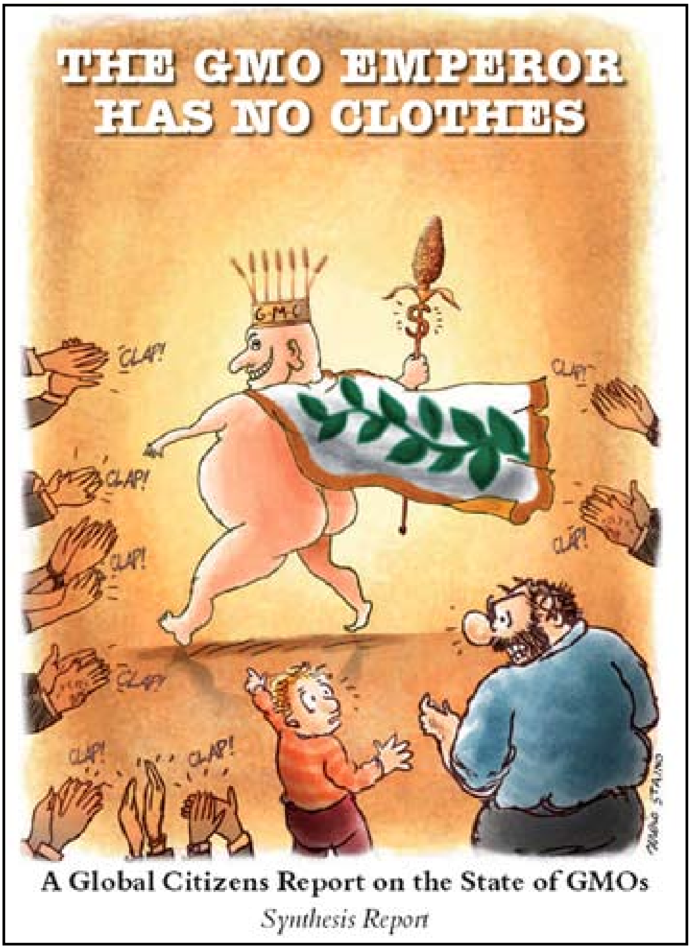

Figure 3. 2011 report by Vandana Shiva *et al.*

calories and nutrition, from a safe food supply, at acceptable cost, from the same area (perhaps up to 10% more) of arable land. This will have to be achieved with less water, and smaller inputs of fertilizer and other chemicals. Again according to the FAO, the foreseeable future will require a 70% increase in food production, a 43% increase in grain production, and a 75% increase in meat production. Specialty crops are part of the solution, in terms of producer economics as well as part of the solution in nutrition, health, and wellbeing of the consumer.

If what we are doing really does matter, the question is: can we broaden the use of advanced science and technologies to include horticultural and specialty crops?

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ROGER BEACHY is the founding executive director of the newly established World Food Center at University of California, Davis; in 2013 he served as the Executive Director of the Global Institute for Food Security at the University of Saskatchewan in Saskatoon, SK, Canada. He is also president emeritus of the Donald Danforth Plant Science Center, and was the first director of the National Institute of Food and Agriculture (NIFA). Prior to this appointment, he served as the founding president of the Danforth Center.

From 1991 to 1998, he headed the Division of Plant Biology at the Scripps Research Institute. He was also professor and Scripps Family Chair in Cell Biology and co-director of the International Laboratory for Tropical Agricultural Biotechnology at Scripps. From 1978 to 1991, he was a member of the Biology Department at Washington University in St. Louis, where he was professor and director of the Center for Plant Science and Biotechnology. His research has produced more than 230 journal publications in virology and virus pathology, and regulation of gene expression in plants.

Dr. Beachy is a member of the US National Academy of Sciences and in 2001 received the Wolf Prize in Agriculture. He is a fellow in the American Association for the Advancement of Science, the American Academy of Microbiology, the National Academy of Science India, the Indian National Science Academy, and the Academy of Science of St. Louis.

He holds a PhD in plant pathology from Michigan State University and a BA in biology from Goshen College.