Editor's Choice Series: The Next Generation of Biotech Crops

Crop genetic modification using traditional methods has been essential for improving food quality and abundance; however, farmers globally are steadily increasing the area planted to crops improved with modern biotechnology. Breakthroughs in science and genetics have expanded the toolbox of genes available for reducing biotic stressors, such as weeds, pests, and disease, which reduce agricultural productivity. Today, plant scientists are leveraging traditional and modern approaches in tandem to increase crop yields, quality, and economic returns, while reducing the environmental consequences associated with the consumption of natural resources, such as water, land, and fertilizer, for agriculture.

The current need to accelerate agricultural productivity on a global scale has never been greater or more urgent. At the same time, the need to implement more sustainable approaches to conserve natural resources and preserve native habitats is also of paramount importance. The challenge for the agricultural sector is to: (1) deliver twice as much food in 2050 as is produced today (Food and Agricultural Organization of the World Health Organization, 2002); (2) reduce environmental impacts by producing more from each unit of land, water, and energy invested in crop production (Raven, 2008); (3) adapt cropping systems to climate changes that threaten crop productivity and food security on local and global levels; and (4) encourage the development of new technologies that deliver economic returns for all farmers, small and large. These are important and challenging goals, and are much more so when real or perceived risks lead to regulatory and policy actions that may slow the adoption of new technology. Optimistically, the adoption of rational approaches for introducing new agricultural and food technologies should lead to more widespread use that in turn will help address the agricultural challenges and also increase the acceptance of modern agricultural biotechnology (Raven, 2008).

In the 12 years since commercialization of the first genetically modified (GM) crop in 1996, farmers have planted more than 690 million hectares (1.7 billion acres; James, 2007) without a single confirmed incidence of health or environmental harm (Food and Agricultural Organization of the World Health Organization, 2004; National Academy of Sciences, 2004). In the latest International Service for the Acquisition of Agribiotech Applications report, planting of biotech crops in 2007 reached a new record of 114.3 million hectares (282.4 million acres) planted in 23 countries, representing a 12.3% increase in acreage from the previous year (James, 2007). Farmer benefits associated with planting of GM crops include reduced use of pesticides and insecticides (Brookes and Barfoot, 2007), increased safety for nontarget species (Marvier et al., 2007; Organisation for Economic Co-operation and Development, 2007), increased adoption of reduced/conservation tillage and soil conservation practices (Fawcett and Towry, 2002), reduced greenhouse gas emissions from agricultural practices (Brookes and Barfoot, 2007), as well as increased yields (Brookes and Barfoot, 2007).

The first generation of biotech crops focused primarily on the single gene traits of herbicide tolerance and insect resistance. These traits were accomplished by the expression of a given bacterial gene in the crops. In the case of herbicide tolerance, expression of a glyphosate-resistant form of the gene *CP4 EPSPS* resulted in plants being tolerant to glyphosate (Padgette et al., 1995). Similarly, expression of an insecticidal protein from *Bacillus thuringiensis* in plants resulted in protection of the plants from damage due to insect feeding (Perlak et al., 1991). Both of these early biotech products had well-defined mechanisms of action that led to the desired phenotypes. Additional products soon came to market that coupled both herbicide tolerance and insect resistance in the same plants. As farmers adopt new products to maximize productivity and profitability on the farm, they are increasingly planting crops with "stacked traits" for management of insects and weeds and "pyramided traits" for management of insect resistance. The actual growth in combined trait products was 22% between 2006 and 2007, which is nearly twice the growth rate of overall planting of GM crops (James, 2007).

The next generation of biotech crops promises to include a broad range of products that will provide benefits to both farmers and consumers, and continue to meet the global agricultural challenges. These products will most likely involve regulation of key endogenous plant pathways resulting in improved quantitative traits, such as yield, nitrogen use efficiency, and abiotic stress tolerance (e.g. drought, cold). These quantitative traits are known to typically be multigenic in nature, adding a new level of complexity in describing the mechanisms of action that underlie these phenotypes. In addition to these types of traits, the first traits aimed at consumer benefits, such as healthier oils and enhanced nutritional content, will also be developed for commercialization.

As with the first generation, successful delivery of the next generation of biotech crops to market will depend on establishing their food, feed, and environmental safety. Scientific and regulatory authorities have acknowledged the potential risks associated with genetic modification of all kinds, including traditional

www.plantphysiol.org/cgi/doi/10.1104/pp.104.900256

cross-breeding, biotechnology, chemical mutagenesis, and seed radiation, yet have established a safety assessment framework only for biotechnology-derived crops designed to identify any potential food, feed, and environmental safety risks prior to commercial use. Importantly, it has been concluded that crops developed through modern biotechnology do not pose significant risks over and above those associated with conventional plant breeding (National Academy of Sciences, 2004). The European Commission (2001) acknowledged that the greater regulatory scrutiny given to biotech crops and foods probably make them even safer than conventional plants and foods. The current comparative safety assessment process has been repeatedly endorsed as providing assurance of safety and nutritional quality by identifying similarities and differences between the new food or feed crop and a conventional counterpart with a history of safe use (Food and Drug Administration, 1992; Food and Agricultural Organization of the World Health Organization, 2002; Codex Alimentarius, 2003; Organisation for Economic Co-operation and Development, 2003; European Food Safety Authority, 2004; International Life Sciences Institute, 2004). Any differences are subjected to an extensive evaluation to determine whether there are any associated health or environmental risks, and, if so, whether the identified risks can be mitigated though preventative management.

Biotech crops undergo detailed phenotypic, agronomic, morphological, and compositional analyses to identify potential harmful effects that could affect product safety. This process is a rigorous and robust assessment that is applicable to the next generation of biotech crops that potentially could include genetic changes that modulate the expression of one gene, several genes, or entire pathways. The safety assessment will characterize the nature of the inserted molecules, as well as their function and effect within the plant and the overall safety of the resulting crop. This well-established and proven process will provide assurance of the safety of the next generation of biotech crops and help to reinforce rational approaches that enable the development and commercial use of new products that are critical to meeting agriculture's challenges.

This issue of *Plant Physiology* begins a 3-month Editor's Choice Series focused on the next generation of biotech crops. The intent of this series is to provide readers with an updated view of the opportunities and challenges that will be faced as we move into the next generations of commercialized biotech crops. As part of this series, several articles will be featured that discuss various technological approaches that will be important in generating these new GM crops, such as RNA interference, protein engineering, and plant transcription factors. Articles focused on stress-tolerant crops, including virus-resistant papaya (*Carica papaya*), drought-tolerant maize (*Zea mays*), environmental risk assessments of stress-tolerant crops, and quantitative trait loci approaches to complex traits, will also be featured. The final set of articles are focused around nutritionally enhanced crops, including a general overview as well as specific articles on altered oils and altered amino acid content. Additionally, review articles discussing the impact of global climate change on agricultural production and molecular breeding approaches are also included in the series. Hopefully you have already noticed the special cover that has been designed for this May issue to kick off the series. The cover features a stunning holographic image of a DNA molecule superimposed on a crop field. This graphic is intended to depict the next generation of biotech crops that will be developed with the knowledge gained from our continued exploration into the secrets of plant genomes as a way to further enhance modern agriculture.

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