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The Challenges and Potential for Future Agronomic Traits in Soybeans

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Soybeans are the primary source of the world's supply of protein and vegetable oil. The demand for increased production of soybeans is forecasted to mirror the world's population growth and demand for protein and edible oil. In order to meet this demand, production acreages are increasing in key global soybean areas; moreover, technologies to increase production efficiency through transgenic trait control of yield-robbing pests and pathogens, while lowering the cost and use of insecticide and other less efficient agricultural practices, are very much a reality. In addition, the increase in more efficient and more sustainable agronomic practices will help fuel some key improvements in soybean quality and new opportunities for agricultural solutions resulting in feed improvements, health benefits through foods, and new industrial opportunities contributing to a more sustainable global environment.

Key words: biotechnology traits, glyphosate tolerance, insect resistance, quality improvement, soybean production, virus resistance.

Overview

Soybeans are grown in many parts of the world and are a primary source of vegetable oil and protein for use in food, feed, and industrial applications (Endres, 1992, 2001). A variety of pests have devastating effects on the agronomics and economics of soybean production, affecting yield and quality of grain and seed; this list of pests includes weeds, insects, fungi, nematodes, and viruses.

One of the best examples of a modern world agricultural technology altering the path of a world commodity crop is in the development of soybeans that are tolerant to the herbicide glyphosate. Unlike previous traits in soybean, the rapid commercial adoption of glyphosate-tolerant soybeans provided tangible benefits to the grower, and enhanced productivity that fueled the trait adoption (James, 2001; Carpenter et al., 2002). Since their introduction in 1996, glyphosate-tolerant soybeans have grown to occupy over 33.3 million hectares—more than 46% of the global soybean acreage. In addition, soybean acreage in Argentina rose from 7 to 11 million hectares, a result likely facilitated by the adoption of Roundup Ready soybeans. The rapid rate of adoption (shown in Figure 1) would likely have been mirrored in other soybean-producing countries if the regulatory, intellectual property, and equity criteria for deployment of agricultural technology had been achieved. The commercial acceptance of glyphosate-tolerant soybeans has set a high hurdle and a new expectation for biotechnology and future soybean agronomic traits.

New traits targeted for soybean production that possess the potential for more sustainable and consistent production continue to be evaluated. The major global soybean production areas for the 2001/02 production season are listed in Table 1 (Soyatech, 2003).

Most of the soybean growing countries in Table 1 and a significant amount of global areas would be beneficiaries of new traits currently being evaluated by soybean research programs. Traits that increase production efficiencies and lower the cost and use of insecticide applications have the highest success due to a direct benefit to the producer.

Agronomic challenges represent opportunities for production enhancement; using biotechnology, several opportunities to promote more sustainable and environmentally friendly agriculture are likely achievable. As soybeans have expanded in the world, soybean pests and diseases have become more severe. Tropical and subtropical climates present environmental and biotic stress environments that favor pest infestations and represent the largest region of opportunity. Work to develop soybeans that are resistant to key insect pests are one example of technology with demonstrated proof of concept (Walker, All, McPherson, Boerma, & Parrot, 2000), and where few if any technical obstacles impair commercialization. Another area of focus has been in the research and evaluation of soybeans that are resistant to viruses (United States Department of Agriculture Animal and Plant Health Inspection Service [USDA APHIS], 2003).

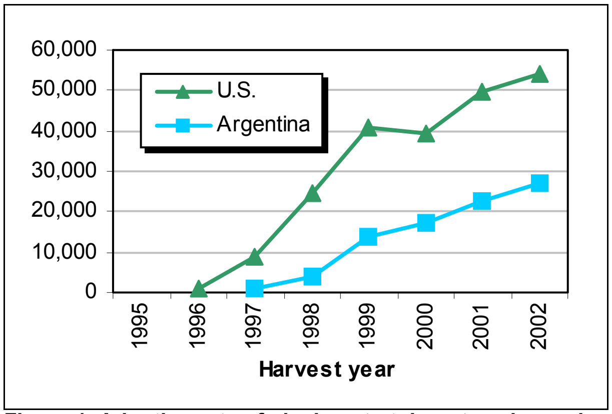

Figure 1. Adoption rate of glyphosate-tolerant soybeans in the United States and Argentina.

Table 1. World soybean production area, 2001/02 growing season.

Country[a]	Area harvest (million hectares)
United States	29.50
Brazil	16.40
Argentina	11.30
China (PRC)	9.10
India	6.00
Paraguay	1.40
Canada	1.00
Indonesia	0.72
Bolivia	0.60
N. Korea	0.31
Italy	0.25
Thailand	0.23
Japan	0.14
Nigeria	0.13
South Africa	0.13
Vietnam	0.13
France	0.12
Former Yugoslavia	0.11
Burma	0.09
Iran	0.09
Mexico	0.08
S. Korea	0.08
Zimbabwe	0.06
Australia	0.05
Subtotal	**78.02**
Remaining world production	0.94
Total world	**78.96**

[a] *Countries with greater than 50,000 hectares reported in 2001–2002 growing season.*

Current Status of Agronomic Traits from Soybean Biotechnology

High application loads of insecticides and fungicides are not a common agronomic practice for soybeans across the industry; however, in many world areas, soybean is a crop that may be challenged by significant insect pests and fungicide pathogens. Biotechnology-derived insect resistance traits in cotton and corn have created the benchmark for the use of biotechnology for controlling key pests in soybean. Among the benefits that growers expect are lowered insecticide use, better control of key insect pests with less scouting and reduced risks of losses due to suboptimal timing of an insecticidal application, convenience to the grower, safety to the applicator, and more consistency in year-to-year performance in a farm pest management program. A broad array of insects feed on soybeans around the world, but the largest impact for pest damage to soybeans occurs in the tropical and subtropical regions. The list of insects that affect productivity in soybeans includes multiple orders in the insect class: lepidopteran, coleopteran, hemipteran, and homopteran pests. Biotechnology traits to control major lepidopteran pests are the furthest developed, showing efficacy against these pests in tropical and subtropical regions. The pests that represent the largest impact to soybean-growing regions include the defoliating insects such as velvetbean caterpillar, soybean looper, sunflower looper, and epinotia. Others, such as bean leaf beetle and piercing-sucking type insects (including green stinkbug, soybean stinkbug, neotropical brown stinkbug, and Chinese aphids), are likely under evaluation. Approaches to identify and introgress resistance loci through conventional breeding methods have been performed with limited success (Narvel et al., 2001). Academic and industrial researchers in the United States have identified Bt proteins and produced transgenic soybeans containing Bt genes that offer resistance to many of these key pests that have global implications (Marking, 2001). Figure 2 shows a Bt-soybean transgenic line that demonstrates resistance to several key lepidopteran pests.

Viruses in soybeans are global pests; there are more than 100 viruses capable of causing an infection in nature. Two key viruses that have devastating effects on yields are the soybean mosaic virus (SMV) and bean pod mottle virus (BPMV; Demski & Kuhn, 1989a, 1989b). In addition, BPMV is a causative agent that leads to poor seed quality.

The development of virus-resistant soybeans using biotechnological methods has been initiated and evalu-

Figure 2. Infestation of a transgenic Bt soybean with velvetbean caterpillar in screenhouses. The nontransgenic control on the right shows extensive defoliation in this screenhouse trial. (Photo provided by Dr. Ted McRae, Monsanto Company.)

Figure 3. Photograph of stem necrosis (*necrose da haste*) caused by carlavirus from a Brazilian soybean field in Sorriso, Mato Grosso.

ated by several groups (USDA APHIS, 2003). Over the past decade, soybean lines that might be resistant to BPMV have been developed by a number of groups (Di, Purcell, Collins, & Gabrial, 1996; Reddy, Ghabrial, Redmond, Dinkins, & Collins, 2001). Similarly, transgenic lines have been generated using the coat protein gene from the soybean mosaic virus to evaluate the ability of soybeans to withstand SMV infection (USDA APHIS, 2003). Results from these studies and work in other crops suggest that biotechnological methods to generate virus-resistant soybeans can be commercially efficacious and have the potential to deliver the same types of benefits in soybean as seen with insect resistance in other crops.

Severe damage can be caused by a number of viruses that may be regionally localized. A recently noted disease of soybean in Brazil (stem necrosis, caused by a carlavirus) has generated considerable concern (Figure 3). The virus is transmitted by whiteflies (*Bemesia* sp.), causes significant damage, and is endemic in areas of the Brazilian cerrado. Developing resistance to devastating pathogens such as the carlavirus will be an ongoing task that will often require the use of biotechnology to confer resistances.

In addition to agronomic traits to enhance production and consistency of production of soybean grain, the quality-improvement traits promise to have an equally important role in leading to new opportunities for soybeans with worldwide deployment potential. Conventional breeding and biotechnology-derived quality traits that may build off of enhancements in production and consistency of production for soybeans are higher oil, higher protein, modifications in essential amino acids and protein compositional changes, changes in oil composition, nutritional traits such as vitamins, and new industrial uses including biodiesel, bio-lubricants, and polymers. The commitment to develop such products is likely to be driven by demand in the large soybean markets (with delays in deployment to secondary soybean production areas and developing countries based upon technology protection) and the seed and processing industry infrastructure. The deployment of biotechnology traits and unique germplasm are dependent upon the development of the infrastructure that supports the investment in time and financial resources to bring these products to the commercial stage in the secondary and developing soybean production regions.

The current opportunities in biotechnology and molecular breeding for soybeans, the tools of genomics for the next generation of soybean products, advancements in enabling biotechnology for soybeans, and worldwide soybean germplasm resources all can play vital roles for the deployment of traits with sustainable soybean production. The direct and indirect benefits for the producer to the consumer range from environmental safety to economic advantages through valuable technology traits such as resistance to insects or viruses. These traits must continue to be a key goal to those involved in research and promoting sustainable agriculture. Development of technologies that lead to increased efficiency and consistency of production is a critical aspect of providing the platform and the path for worldwide deployment of higher value soybeans.

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