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A Soybean Biotechnology Outlook

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Soybean has been closely associated with developments in science and technology, which established it as the world's leading source of vegetable oil and protein. Soybean will remain a candidate for further development via biotechnology based upon its genetic and product potential if research funding is adequate and includes a strategic partnership between the public and private sectors.

Key words: soybean, *Glycine max*, research funding, genomics, oilseed processing.

There exists perhaps no better example of the link between science, economics, and the development of a crop plant than the soybean (*Glycine max*). Science and technology of the last century created this important world oilseed crop, and biotechnology and the life sciences of the future will likely determine its future fate.

Soybeans have been closely associated with human activity since prehistoric times. Originating in Asia, the soybean was introduced to North America in 1765, and was used by the pioneers of the temperate and humid eastern US as a vegetable and forage crop (Hymowitz, 2003). It was not until the early 20th century that developments in plant breeding and industrial processing transformed soybean into the dominant global crop it is today.

Past Reliance upon Science and Technology

Plant breeding enhanced the adaptation of soybean to a broad range of temperate environments; varieties are now grown as far north and south as 50°. Directive plant breeding was also responsible for slowly tipping the balance of use and value by selecting for seed rather than overall biomass yield. In 1941, for the first time, more soybean was harvested for grain than hay (United States Department of Agriculture National Agricultural Statistics Service [NASS], 2003). Oilseed processing was another important concurrent technological development (Erikson, 1995). In the early 20th century, continuous screw press development was particularly adapted to high oil seeds (such as cottonseed and flax); by the middle of the century, development of solvent extraction for efficient separation of oil from soybean meal was significant. Plant breeding and solvent extraction processing were separate but synergistic technologies that transformed soybean into the dominant source of vegetable oil and meal by the end of the century, both in the US and worldwide. Today, soybean is planted on more than 70 million acres annually in the US—more than any other single crop except corn (in most years; NASS, 2003). Furthermore, at the dawn of the 21st century, soybean accounts for 56% of all global oilseed production (Soyatech, 2003), an industry-leading 29% of all vegetable oil production, and 67% of all vegetable protein meal production. In all, soybean shows a remarkable record of achievement, resulting from a combination of science and technology with development of a new crop and industry.

Genetic and Product Potential

One of the first and most important applications of DNA science is quantifying and mapping the genetic code of humans, plants, and animals. Although still in its infancy, the process to date has yielded new thinking—some of it counterintuitive. For example, much of the genetic code of life is shared identically within species, across species, and across kingdoms. This fact has no doubt influenced the national effort to document and map plant genomes. In 2002, the National Plant Genome Initiative (NPGI, 2002) introduced the concepts of "reference species" and of using the revealed commonality of life to spawn "translational agriculture." In short, the NPGI suggests that focusing mapping resources on a few carefully chosen plant species could yield information and clues that are transferable to many other plant species. The genetic sequences common to all plant genomes do not need to be mapped repeatedly. With the concurrent advent of computer networks and coordination, the work of plant genome mapping can be decentralized across many labs and reconstructed in shared databases. Verification and testing across species for shared genetic traits can further advance understanding and subsequently plant improvement.

The NPGI initially suggested candidates from the Poaceae (grasses), Fabaceae (legumes), and Solanaceae (tomatoes, potatoes) families—the key plant families that represent the largest quantity of economically important plants. Rice, maize, and tomato are among the chosen few. Among the legumes, *Medicago truncatula* (an annual relative of alfalfa) is already serving as a useful reference species. The most recent NPGI annual report suggests that a few additional plant candidates of economic importance—including wheat and soybean—warrant more attention. Such additional attention could prove important to soybean development using biotechnology as a tool in plant genetic improvement. Because the soy genome has twice the number of base pairs as *Medicago*, it would seem reasonable to enhance and coordinate the work already begun on mapping the genetic code of soybean to boost it and all legumes. Despite the broad and rich genetic diversity of *Glycine* species, modern soybean varieties can be traced back to a minute fraction of the germplasm—most modern varieties come from one of only seven parental sources (Hymowitz, 2003). Accelerating the knowledge of the soybean genome by including it as a key reference species within the NPGI seems an important step for the future of soybean.

Just as solvent extraction processing helped create the soy oil and meal market in the 20th century, new processing and other postharvest technologies will most certainly help create new uses and markets in the 21st century. Already soy oil is being considered as the base carbon ingredient in the manufacturing of biodiesel, a liquid fuel for use in diesel engines. Coupling the rapid advancements in breeding via biotechnology with new discoveries in engineering and nanotechnology could create products and industries not yet known today. Soybean could serve as a unique and valuable plant source for a host of novel, health-promoting food products. Concerns about the increased incidence of obesity and diabetes in the United States have focused attention on enhancing protein consumption, particularly that of soy-based foods. Furthermore, soy products seem likely candidates to serve as a key carbon source, as our society and economy begin the transition from hydrocarbon-based energy and materials science to that of renewable carbohydrates.

Another important attribute of the success of soybean relates to its efficiency at nitrogen fixation and its compatibility with grasses in crop rotation. Few major crop production regions in the world lack a compatible and highly adapted grass/legume sequence. Although the US Midwest has been called the “Corn Belt,” it was the advent and development of soybean as a commercially viable crop that supplied the biodiversity, the nutrients, and ideal temporal sequence that made corn and the region successful. Further improvements through breeding and biotechnology are already increasing soybean stress tolerance and adaptatability such that it is expanding into many environments previously thought too hot, cold, wet, or dry. Soybean is increasingly playing a larger role in crop rotations with rice and wheat around the globe.

Table 1. United States public research expenditures and planted acreage of major crops in 2001.

Crop	Total public research expenditures[a] (millions)	Planted acreage[b] (millions)	$/acre
Wheat	$96.7	60	1.61
Corn	$110.4	75.8	1.46
Soybean	$88.6	74.1	1.20

[a] *USDA Current Research Information System (2003)*
[b] *USDA National Agricultural Statistics Service (2003)*

Research Funding

Science and technology research requires adequate funding for discovery, development, and marketing of new and improved products. Although both public and private research funding are critical for development of crops and products, reliable information about specific topics is available only from the public sector. Examination of the relative investment among major crops in the US reveals fairly steady expenditures over the last decade (accounting for inflation). Soybean ranks slightly lower than both wheat and corn in annual per-acre research investment (when normalized by planted acre). Given the potential importance of future soybean products to multiple new food and nonfood markets and the potential advancements in biotechnology, it would seem that a greater investment in soybean research would be required to keep it firmly in the future.

The role of the public land-grant university in the future of soybean development will likely change given the changing nature of science and technology. In the past, the biological development of improved soy genetics, varieties, and production was contributed mostly by the public sector, whereas the private sector contributed soybean oilseed processing and product development. Looking ahead, both biotechnology and evolving intellectual property rights suggest a different kind of public/private sector relationship. One possible scenario would suggest more of a strategic discovery and development approach. The public sector—such as land grant universities—would contribute the initial discovery and proof of concept. Such discovery could include novel genes, traits, new pathways, or value as a food, feed, or biofuel. The private sector would license and develop the most promising of combinations of proven discoveries and deliver the final products to the consumer. Such a relationship allows both public and private sectors to maximize their strengths.

A Vision for the Future

Just as 20th century biological and engineering technologies created the modern soybean crop and industry, the 21st century will spawn its own new economically important plants and products. A metaphor for the 20th century would certainly have to be the assembly line, which by its very nature required compartmentalization of tasks, specialization of skills, and uniformity of materials. Discoveries of the next century are poised to move beyond these requisites. Differentiation, decentralization, and customization are the traits likely to result from future advances in communication, biotechnology, and engineering.

The brightest possible outlook for soybean will happen only if those in science and industry resist the temptation to look back, but instead accept the exciting challenge of looking forward to new opportunities, fitting the coming new metaphor. *Glycine max* has the genetic diversity for differentiation, produces a balanced combination of protein, fat, and carbohydrate to serve as a valuable food, feed, and bio-feedstock, inhabits cropping systems as a valuable contributor of nitrogen, and possesses other agronomically complementary traits. Given the coming advancements in biotechnology, the future of soybean will require the sound use of genetic resources within *Glycine,* adequate funding for research and development, and a clear vision of the opportunities that lie ahead.

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