Chapter 1
Molecular Genetic Approaches to Maize Improvement – an Introduction

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In the following chapters prominent scientists will discuss the recent genetic improvements in maize that have brought us to this point, as well as the potential for future improvement. A review of historical improvements is an instructive base from which to launch this discussion.

Let's look back to 1944, when much like today, the United States was planting as many acres of maize as possible and trying to get as much yield as possible from every acre. According to the US Department of Agriculture, about 85 million acres in the US were planted to maize in 1944 – about the same acreage as 2007. The total production of maize in the US in 1944 was 2.3 billion bushels. In 2007, it was 13.1 billion bushels – that's an increase of 470%. The average yield in 1944 was 33 bushels per acre, production typical of that era. That figure has jumped by 360% to 151 bushels per acre.

Given this stark contrast, the question we must ask ourselves is, how did we come so far so fast? What are some of the factors contributing to higher maize yields? Will these trends continue?

From a historical perspective, the most striking advance in maize production in the last century was the introduction of hybrids. By inbreeding and crossing the resultant lines, maize breeders were able to produce hybrid offspring with higher yields through the phenomenon known as heterosis or "hybrid vigor." In order to harness the power of hybrid vigor, breeders initially began "double-crossing," or crossing two inbred parents at the same time as two other inbred parents. Resulting hybrids are then crossed together to produce a hybrid with the characteristics of all four parents. This method was used into the 1960s, by which time inbreds had improved to the point where single cross hybrids became standard in US maize production and have been widely adopted around the world.

Along with advances in breeding, the steady rate of yield gain in maize benefited from improvements in nutrient management, tillage practices and chemical

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methods for weed and insect management. The agricultural sector built upon these developments by establishing commercial soil and plant testing laboratories and producing new farm implements for no-till systems. Crop consultant enterprises developed to help implement these more information-intensive crop and soil management practices (Duvick and Cassman 1999). The historically strong connection between public institutions (universities, extension services, USDA, etc) and private industry (seed, crop chemical and equipment producers) served as a template for the integration of different production advances, enabling the industry to leverage these technical advances into rapid yield gains. More recent advancements in precision planting equipment and variable rate nutrient delivery ensure these productivity increases will continue.

The application of biotechnology techniques has facilitated rapid progress in breeding using molecular markers. In the last two decades, multiple generations of DNA detection technology were introduced: restriction fragment length polymorphisms (RFLPs), simple sequence repeats (SSRs), amplified fragment length polymorphisms (AFLP) and single nucleotide polymorphisms (SNPs). These technologies moved quickly from theory to practical applications in breeding. The parallel development of computing capability within this time frame also facilitated the ability to fully exploit molecular markers. In addition, development of laboratory automation technology to allow high-throughput genotyping provided the scalability necessary to make use of molecular markers an integral part of commercial maize breeding programs. Routine application of molecular markers in maize breeding programs should lead, by some estimates, to at least a doubling of the rate of genetic gain compared to conventional breeding programs without markers. In addition, the use of molecular markers has greatly facilitated the introgression of transgenic traits into commercial maize germplasm, which has allowed the rapid adoption of transgenic traits in highly adapted germplasm around the world.

The development of maize transformation technology in the early 1990s rapidly accelerated the application of transgenic approaches to improvement of maize production. The first insect-protected maize plants containing genes to confer resistance to European corn borer and other lepidopteran pests were commercialized in the mid-1990s. Since then, adoption of first-generation biotechnology traits, for insect protection and herbicide resistance in maize, has been rapid, not only in North America, but in other maize-growing areas around the world. In particular, the use of maize containing three stacked genes or multiple traits for lepidopteran insect control, corn rootworm control and herbicide tolerance for more efficient weed control has increased dramatically. By 2007, transgenic maize was planted on more than 30 million hectares in 16 countries. In 2008 more than 80 percent of U.S. maize crops contain at least one biotech traits. In addition to higher yields, these transgenic maize hybrids contribute to reduction in greenhouse gases and pesticide use. While the adoption of first generation traits in maize has been rapid, the next generation, currently in development, holds even more promise. These traits are designed to help maize continue to grow under drought conditions, more efficiently use nitrogen, produce even higher yields, enhance protection against insects and other pests, and improve grain quality for food, animal feed and biofuels.

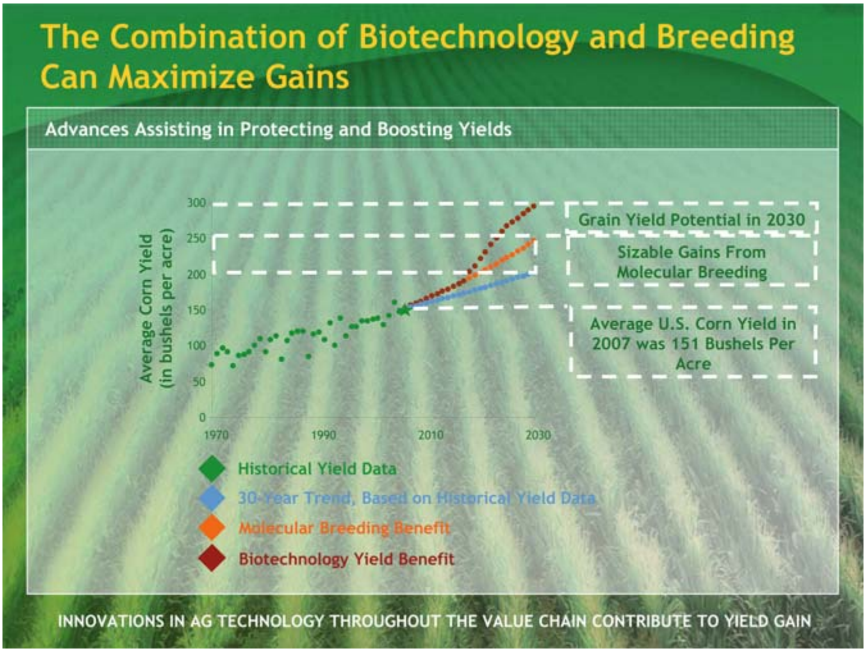

Fig. 1.1

Together with improved farming practices, maize breeding and biotechnology have allowed us to continuously improve productivity to the current US average of 151 bushels per acre. At the same time, maize production has become increasingly sustainable in terms of land, fertilizer and water use. A doubling of yield per acre is a doubling of land use efficiency. Farmers are producing twice as much maize on the same amount of land, and, in the past three decades, sustainability metrics in maize production have improved across the board. For instance, nitrogen fertilizer application rates per acre of maize have held constant while yields have increased by 50%.

New technologies continue to increase our understanding of maize. The complete DNA sequence of the maize genome, along with more comprehensive transcriptome, proteome and metabolome information, will continue to drive innovations in molecular breeding and biotechnology. These additional layers of information help to further unravel the complexities of how genes and gene networks function to produce productive maize plants. This knowledge will lead to improved predictions and capabilities to assemble native gene variation through molecular breeding as well as more optimal gene selection and regulation in the development of future biotechnology products.

In the chapters that follow, leading scientists discuss the recent genetic improvements in maize that have brought us to this point, as well as highlight the immense potential for future improvement. One theme clearly emerges from the text: The pace of new innovation continues to accelerate . . . from the development of more powerful breeding tools that are increasing the yield gains . . . to the rapid discovery of new transgenes that will further boost yields, mitigate production risks, promote more sustainable production practices and improve grain composition and nutritional content. The effective and rapid integration of these innovations and tools is breathtaking, and this promises to continue to both further increase maize yields in the US and to extend these gains rapidly to other maize production areas around the world, including Asia and Africa. At the same time advances in maize serve as an important roadmap for increasing yields in other crops, including rice and wheat.

In a world with increasing global need and expectation for food and energy security, the pace of technology and yield advances in maize takes on even greater importance. From the chapters in this book, it is clear that we have the genetic tools based on genomics-based breeding and second-generation biotech traits, together with the continued gains from improved agricultural practices and production systems, for the industry to once again double maize yields to 300 bushels per acre.

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