1 Introduction: Biotechnology of Major Cereals

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The world has over 50,000 edible plant species but just 15 crops contribute 90% of the world's food energy intake, with three cereals, rice, maize and wheat, making up two-thirds of this (FAO, 1995). Ranked on the basis of harvested mass, the top five cereals in the world are maize (corn), rice, wheat, barley and sorghum. However, the commercial application of biotechnology over these five species is heavily skewed. Only in maize are there genetically engineered varieties currently marketed to growers. There is plenty of applied research and field testing in the other crops, and this introduction, along with the other chapters in this book, analyse the current status and future role of biotechnology in applied research and development of improved varieties for these key five cereal species.

A cereal is a domesticated grass (a monocotyledonous angiosperm in the family Poaceae (also known as Gramineae)) grown for its small, edible seed. Cereal grains have been a significant component of human diet for thousands of years and have played a major role in shaping human civilization. All cereals have a starchy endosperm, an embryo/germ and various bran and husk layers. Cereals are eaten by humans and animals as whole grains or milled into various fractions, processed and cooked to produce a wide range of food products. They are a major source of starch and other carbohydrates but also provide significant protein, micronutrients, minerals and fibre.

Figure 1.1 shows the steady yield increase of all cereals over the past 30 years in selected agricultural regions of the world. Although yields are increasing slowly in all regions indicated, North America, South America and China show a higher rate of increase than other regions. Clearly, there are many factors that determine yield of various crops, but it is tempting to speculate whether the general adoption of biotechnology and/or F1 hybrids in these areas can partly explain the differences.

The harvested mass per unit area (yield) is the most important breeding target for all crops. However, there is compelling evidence that the increase in genetic yield potential from breeding is falling behind what is necessary to maintain global food security. There is a consensus from many agencies that a doubling of crop yield is needed by 2050 (FAO, 2009; OECD/FAO, 2012). However, current rates of yield increase are not achieving this goal. Ray *et al.* (2013) used a newly developed crop yield and area harvested database covering 13,500 world

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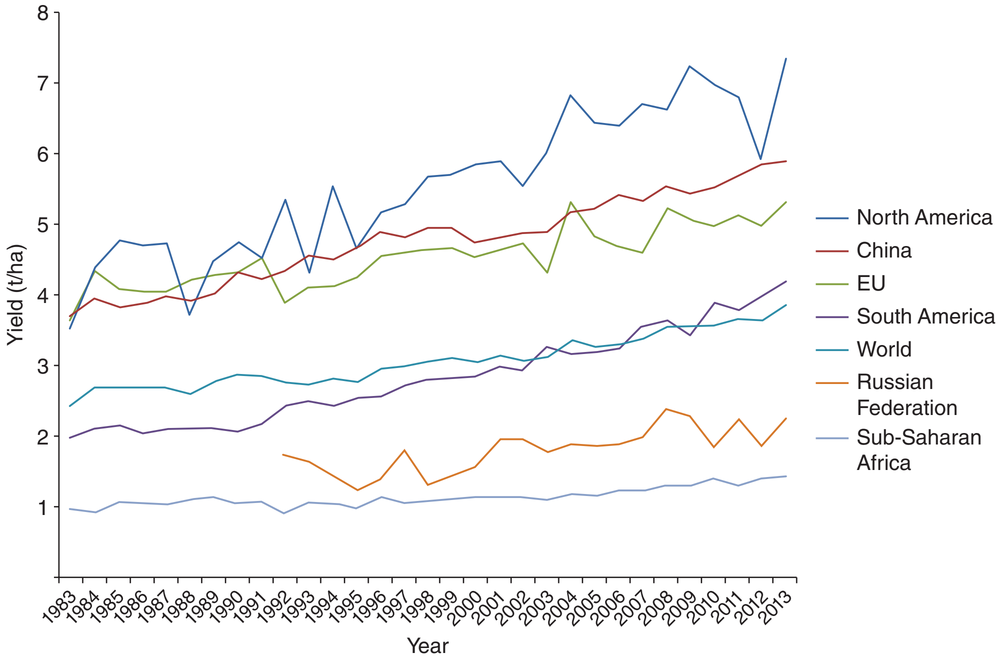

Fig. 1.1. Cereal yield, kilograms per hectare of harvested land, for maize, rice, wheat, barley, sorghum, oats, rye, millet, buckwheat and mixed grains over the past 30 years (no data from the Russian Federation prior to 1992). (Redrawn from data in World Data Bank World Development Indicators: http://data.worldbank.org/. Regression lines for North America, China, European Union (EU) and South America fitted by eye.)

economies from 1961 to 2008 to survey the trends over the past two decades. They conclude that the major crops are failing to achieve the 2.4% rate of crop production growth per year that is necessary to secure a doubling of agricultural production by 2050 (Fig. 1.2). Thus, there is a need for breakthroughs in genetic yield potential to complement the incremental steps typical of conventional breeding programmes.

This challenge for plant breeders and growers comes at a time when our understanding of genomics, transcriptomics, proteomics and phenomics is expanding rapidly. Advances in marker-assisted selection, *in vitro* cellular techniques and recombinant DNA technologies are underpinning major innovations in plant breeding. The full range of 'biotechnologies', including genome editing, is well placed to play a significant part in meeting the challenge of global food security.

For the major crops, especially those that can be developed as F1 hybrids, and for economically important traits, there is scope for genetic engineering to play a significant part in future plant breeding; at least in those regions of the world with functioning regulatory oversight. Of the five major world cereals, only maize has been fully adopted as a biotech crop with an estimated 55.2 million hectares (Mha) of biotech maize grown in 2014. Chapter 2 in this book by Wu *et al.* describes the recombinant DNA techniques and transformation methods used by the commercial maize biotech sector, and Chapter 3 by Coram *et al.* details the significant global adoption of genetically engineered maize and surveys current traits and future trends. Maize is a relatively demanding crop in terms of its biology, and there has been recent interest in model monocots for the C_4 grasses. Chapter 8 introduces the species *Setaria viridis* and describes the excitement regarding its development as a research model for important food crops such as maize.

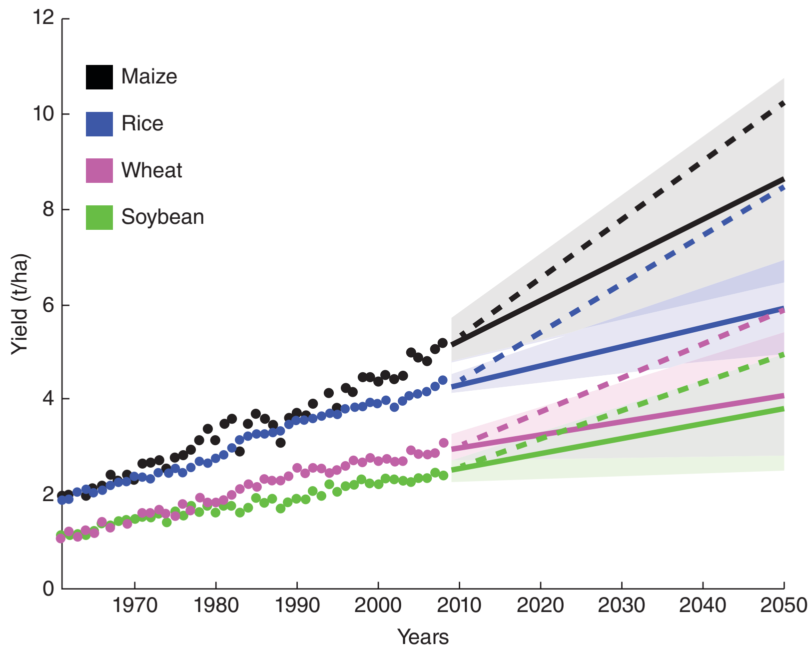

Fig. 1.2. Global projections. Observed area-weighted global yield 1961–2008 shown using closed circles and projections to 2050 using solid lines for maize, rice, wheat and soybean. Shading shows the 90% confidence region derived from 99 bootstrapped samples. The dashed line shows the trend of the 2.4% yield improvement required each year to double production in these crops by 2050 without bringing additional land under cultivation, starting in the base year of 2008. (Reproduced under Creative Commons Attribution License from Ray, D.K. *et al.*, 2013.)

Despite the global significance of rice, wheat and barley as commodity crops, there are no genetically modified (GM) varieties currently being commercialized. Roundup Ready wheat came close to market in the USA and Canada in the early 2000s, and there are various lapsed authorizations for GM rice varieties but none are currently in commercial production. Current applied research into high beta-carotene varieties of rice (Golden rice) along with insect-resistant traits may revive the interest in biotechnology rice breeding. Chapters 5, 6 and 7 by Harwood, Sparks and Jones, and Slamet-Loedin and Macovei respectively, cover the methods, target traits and other relevant issues for barley, wheat and rice.

Sorghum is the fifth largest cereal crop worldwide and is grown in many countries, including Africa, Asia and the Middle East, where it is used to make unleavened bread and porridge or is processed into drinks and speciality foods such as popped grain and beer. The USA is the world's leading producer; however, most of the sorghum produced there and in Latin America is used as livestock feed. The specific breeding challenges and the current trends in applied sorghum biotechnology research are covered by Anami *et al.* in Chapter 4.

Molecular and *in vitro* cellular techniques that provide refinements to conventional recombinant DNA technologies are important to drive future innovation. The exciting prospects of genome editing, the routine production of doubled haploids and the advantages of transforming the chloroplast genome are examples of such developments that are described by Jones, Karaoğlu and Salantur, and Samnakay in Chapters 9, 10 and 11, respectively.

Target traits for biotechnology are covered with respect to the particular crop in question throughout the chapters. However, the specific challenges of developing insect-resistant plants via RNAi, the issues facing food manufacturers regarding the potential carcinogen, acrylamide, the opportunities for engineering the cereal endosperm and the biotechnology approaches to freezing tolerance in cereals are dealt with by Yu *et al.*, Halford and Curtis, Opsahl-Sorteberg, and Soltész *et al.* in Chapters 12–15, respectively.

A review of the biotechnology seeds business concluded that North America was the largest regional market for commercial biotech seeds, with market revenue of US$13.96 billion in 2013. The global market was valued at US$21.45 billion in 2013 and is expected to reach US$42.53 billion by 2020. Although GM maize is second to soy as the largest-consumed GM seed, it is expected to witness fastest growth, with an estimated compound annual growth rate of 11% from 2014 to 2020. An overview of the commercial biotechnology landscape, along with recent mergers and acquisitions, is described by Dunwell in Chapter 16.

Despite the challenges to agriculture posed by biotic and abiotic stressors, economics and societal expectations, I am confident that global agriculture will continue to produce adequate supplies of nutritious food. Our understanding of plant and animal genomes and our increasing ability to predict or to screen the outcomes of specific crosses better means that plant breeding, including biotechnology in its broadest sense, will play a significant part in future farming.

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