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EDITORIAL

Technological perspectives for plant breeding

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Introduction

New Breeding Technologies? For some, both inside and outside the scientific community, this phrase is synonymous with gene editing—or used exclusively to describe the application of CRISPR/Cas9 to plant improvement. Much as, historically, the term 'biotech crops' has been hijacked to only mean crop plants produced using genetic engineering.

However, 'breeding technologies' refers not only to genetic modification using techniques of molecular biology, but also to a vast number of other techniques developed for breeding via the application of scientific advancements emanating from disciplines such as computer science, plant biology, statistics, automation, robotics and artificial intelligence. This concept is not new: in reality, technology has been a feature of crop improvement since early in the last century.

With the development of genetics as a stream of biological sciences, it is evident that many major advances were first delivered in plants. The fathers of genetics and selection, Gregor Mendel and Charles Darwin, were both keenly involved in the improvement of plants; hence, this is not really surprising. Plants were considerably easier and faster to manipulate genetically than animals, with inherent advantages such as shorter generation times, the potential to produce very large populations and an ability to manipulate genetic recombination by selfing, outcrossing or both.

Within the first three decades of the 1900s, the harnessing of inbreeding and hybrid vigour could best be described as the theoretical genetics leading to agriculturally transformative breeding science. Theoretical genetic principles were developed into tangible and widely accepted applied plant breeding outcomes. In the mid-twentieth century, the development and understanding of tissue culture, polyploidy and quantitative genetics segued into the molecular understanding of genes and technologies to manipulate and transfer them from beyond the plant kingdom. With the reduction in biological genetic traits to chemical/molecular entities or nucleic acid bases, the advances in digital sciences and automation, and the ability to share data electronically in seconds, the twenty-first century breeding teams have an unprecedented toolkit.

As early as the 1990s, molecular markers were implemented for the selection of better lines in plant breeding (Tanksley et al. 1989); genomics-assisted breeding was suggested to enhance precision and efficiency in crop improvement (Varshney et al. 2005). In recent years, however, given the contribution of multiple disciplines to advancements in plant breeding, the role of a plant breeder has been largely transformed from that of a sole decision-maker based on phenotypes or markers to a role of leadership or contribution to a multidisciplinary team. The toolkit these teams have at their disposable would have been unthinkable to a plant breeder from 50 years ago, but today this represents one of the most compelling examples of the delivery of science in the modern world. The delivery itself is deceptively simple, in the form of a propagule: a seed, a cutting or a tuber. With appropriate, modern and sophisticated management, that propagule allows farmers to deliver higher yields and better quality, and to do so more efficiently and cost-effectively than at any other time in history.

This special issue on 'New Technologies for Plant Breeding' contains a collection of review and perspective articles, from leading researchers in the field, that highlight opportunities to exploit new technologies in crop research and breeding programs.

Marker-assisted selection for major genes has had a major impact in plant breeding, but the model of implementation is changing with the emergence of new technologies. Cobb

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et al. (2019a) use rice as an example to show how new developments and processes can be integrated to deploy more efficient strategies for utilising genetic variation. Similarly, Andorf et al. (2019) present the progress in maize breeding by integrating rapid technological advances in sequencing and genotyping technology, transformation including genome editing and doubled haploid technology. Furthermore, Sánchez-Martín and Keller (2019) outline future applications and innovative strategies to combat diseases of major cereal crops. To deliver an open-access research platform to facilitate gene discovery across cereal species, Mace et al. (2018) present the 'Sorghum QTL Atlas'. Whilst most crops now have a reference genome, there is a growing need for 'pan-genomes' to capture the full diversity in crop species. Monat et al. (2018) demonstrate this concept in barley. The availability of sequence information has given rise to more efficient breeding strategies, and Varshney et al. (2018) provide valuable insight into sequencing-based breeding with emphasis on legumes crops. Connecting genome structural variation with complex traits represents a new challenge emerging from more detailed knowledge about complex crop genomes, and Gabur et al. (2018) present some innovative strategies to address this issue in polyploids. Voss-Fels et al. (2018) review concepts to further improve the power and efficiency of genomic selection technologies, whilst Rembe et al. (2018) present a strong case on how reciprocal recurrent genomic selection strategies could assist hybrid breeding in wheat. When aligned with principles of quantitative and Mendelian genetics, new plant breeding technologies can lead to a step change in agricultural productivity (Cobb et al. 2019b).

A tool that has recently been in the spotlight, speed breeding, provides an opportunity to turn over plant generations faster. The opportunity to apply speed breeding to rapidly improve orphan crops is discussed by Chiurugwi et al. (2018). The need for speed is an ongoing quest for plant breeders. Bettgenhaeuser and Krattinger (2018) highlight how advances in genomics now allow the rapid cloning of genes, which can quickly deliver an arsenal of easy-to-deploy traits for the modern plant breeder. Blary and Jenczewski (2018) provide examples of how to increase the frequency of crossovers during meiotic recombination and strategies that could be implemented into breeding programs for more rapid achievement of desirable recombinations.

Finally, the public are becoming more and more interested in where their food comes from and there is a growing need for breeders to tap into this public interest. Such an example is provided through the '1000 Gardens' soybean project (Würschum et al. 2018), which shows how citizen science can engage non-scientists in breeding whilst also contributing knowledge useful for breeders. Also in the public eye is genome editing. Given the recent ruling from the Court of Justice of the European Union regarding genome editing, Eriksson (2018) outlines the evolving EU regulatory framework for GMOs and discusses potential routes for the regulation of plant varieties developed using precision breeding approaches like CRISPR/Cas9. The next decade of plant improvement will harness these powerful technologies to enhance the speed and impact of better genotypes for farmers and consumers worldwide. These are exciting times for scientists applying their knowledge and skills to the betterment of everyone agriculture, food security and development goals.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Ethical standard This article does not contain any studies with human participants or animals performed by any of the authors.

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