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Speed Breeding: A Look at More Crops in Less Time

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Abstract

Traditional crop breeding necessitates a significant amount of time, area, and resources for selection, as well as the following crossing of suitable plants. One of the most important bottlenecks in plant breeding and research is the length of the seed-to-seed cycle. Speed breeding (SB), which primarily relies on photoperiod extension, temperature control, and early seed harvest, has the potential to accelerate the rate of plant improvement in this context. The SB methods are being expanded to short-day plants to shorten the generation interval time, as they have been proved in the case of long-day plants. SB methods are flexible enough to align and integrate with a variety of research goals, such as population development, genomic selection, phenotyping, and genomic editing. In this overview, we look at the various SB approaches and how they might be used to speed up future plant improvement. Despite the fact that SB has been widely utilised in plant phenotyping and the pyramiding of numerous traits for the production of novel crop varieties, it faces a number of obstacles and limits. The aforementioned limits, however, can be overcome by further optimising SB methods for essential food crops and integrating them into plant breeding pipelines

Keywords: Genetic gain; Single seed descent; Breeding cycle

Introduction

The present human population is expected to be over 7.8 billion people, with a projected increase to nearly 9.9 billion by 2050. Climate change, which includes rising temperatures, more frequent floods, and drought, is expected to result in new diseases and pest outbreaks, necessitating a quick plant breeding response. To ensure global food security, scientists stressed the urgent need to increase the current rate of genetic gain of critical food crops [1]. Accelerated crop breeding pipelines will be required to increase the rate of genetic gain and allow for the rapid delivery of enhanced crop types. Plant breeding can be accelerated, as suggested by the breeder's equation, by optimising elements that influence genetic gain per unit time, particularly the breeding

cycle time. Plant breeding techniques such as single-seed descent and shuttle breeding have been used to alter the speed of plant lifecycle turnover since the 1940s [2]. Researchers have recently experimented with controlled-environment (CE) growth conditions to shorten the plant lifecycle even more. Accelerated single-seed descent, rapid generation cycling (RGC: more breeding cycles per year using DNA marker technology), fast generation cycling, and rapid generation turnover are all examples of speed breeding techniques. Since the early twenty-first century, this suite of SB techniques has been used to achieve up to three-fold annual generation turnover in economically and scientifically important model, crop, and pasture families, including Poaceae, Fabaceae, and Brassicaceae, compared to conventional generation advancement systems [3].

The creation of crosses, population mapping, and evaluation of agronomic qualities of relevance are all examples of speed breeding approaches that can be utilised to speed up the breeding process. Researchers modify day/night temperature, available light spectrum and intensity, and photoperiod duration to minimise time to floral initiation and expedite embryo development and seed maturity in plants cultivated under CE conditions. Light is given special attention, with plants responding to changes in light duration and quality by shortening their flowering time [4]. Artificial electric lamps have been used to accelerate plant growth and development for a long time. Since then, photoperiod extension has been routinely utilised in long-day species to control blooming timing. The introduction of modern LED lighting systems aided efforts to speed up lifecycle turnover by allowing for the adjustment of wavelength composition to trigger light responses such as shade avoidance and support rapid flowering growth. The availability of a low-cost growing chamber design demonstrates the SB 'recipe's adaptability, which may be modified to meet local needs and resources [5]. Rapid phenotyping in wheat and the investigation of numerous disease-resistance features in European two-rowed barley have been made possible thanks to SB technology. The development of herbicide-tolerant chickpea and the introduction of beneficial allelic diversity from wild relatives in lentil has been hastened because to a combination of SB technology and marker-assisted selection (MAS). These practical breeding results demonstrate the entire spectrum of SB approaches' ability to significantly speed genetic gain [6].

SB Systems with Flexibility for Fast-Tracking Applied and Basic Research

In vivo–in vitro cycling or full in vitro lifecycle turnover were used in early SB activities. The fully in vivo systems, on the other hand, have been the most commonly used in improvement projects. The researcher demonstrated three potential SB facilities that could be customized based on resource availability. SB I consisted of CE plant growth chambers with a photoperiod of 22 hours given by white LED lights, far-red bulbs, and ceramic metal hydrargyrum quartz iodide bulbs, as well as a temperature of 22 degrees Celsius during the day and 17 degrees Celsius at night. Wheat (Triticum aestivum, T. durum), barley (Hordeum vulgare), and purple false brome (Brachypodium distachyon) blossomed in half the time as controls grown under uncontrolled glasshouse settings during spring and early summer when cultivated under these conditions. The faster growing conditions had no effect on germination rates or seed viability, demonstrating the technology's potential for rapid crop development. SB II was a slightly modified arrangement that used the same temperature settings as SB I but with a 22-hour photoperiod provided by high-pressure sodium vapour lamps. SB II also included the harvesting of immature seeds as well as cold treatment to speed up the generation process. Under SB circumstances, wheat, barley, canola, and chickpea plants showed rapid plant development and uniformity in time to anthesis when compared to control cultivars cultivated in same glasshouse settings without supplemental

lights. By raising temperature, several generations can be completed in a plant breeding programme in a short amount of time, and SB approaches in general use late-spring temperatures. Similarly, for optimal plant development and breeding, a humidity level of 60–70% is advised. In comparison to field or typical glasshouse settings, the combination of photoperiod, temperature, and humidity in a greenhouse chamber accelerates plant development.

SB Research and Breeding Applications

The generation of biparental and more complicated mapping populations, pyramiding traits, hastening backcrosses, phenotyping adult plant attributes, mutant investigations, and genetic transformation experiments are all examples of SB applications. Recent research has demonstrated the value of combining modern techniques with SB for crop improvement, including as gene editing, high-throughput phenotyping and genotyping, genomic selection (GS), and MAS. Furthermore, by planting them at high plant densities, the cost and space requirements for creating a large number of inbred lines can be reduced. SB aids in the resolution of problems connected with double haploid (DH) technology, such as low germination rates, weak vigour, and even deformed development. Due to the many meiotic events that occur during repeated fertilisation and the associated greater recombination frequency, recombinant inbred lines (RILs) generated following multiple generations of self-fertilization can be preferable over DH for genetic mapping purposes. Similarly, SSD can advance and evaluate segregating generations in a short period of time under SB conditions, which saves time and money as compared to the traditional pedigree breeding method. This method proved successful in decreasing the generation period, resulting in a three-fold increase in generation turnover compared to shuttle breeding. Agronomic trait phenotyping can be done in conjunction with SB; however caution is advised because phenotypic expression can be skewed under CE circumstances. As a result, field crop phenotyping under SB should be verified in the field to ensure that trait expression is linked to the field environment. For example, in pea grown hydroponically to integrate with SB conditions, boron tolerance was reliably distinguished, and in wheat, SB procedures were integrated with phenotype screening such as disease resistance. When recorded in SB circumstances, some agronomic parameters, such as flowering time and plant height, are connected to field-based determination and production, and hence can aid indirect selection. Species can show genotypic variations in response to rigorous growth conditions after SB has been established. Intensive growth conditions often result in low seed output, which can limit field evaluations in the future. Low seed quantities can be overcome with the use of next-generation sparse phenotyping field trial designs. Excessive photoperiod can stifle plant growth and is linked to photo-oxidation, increased starch production, and raised stress hormone levels. Similarly, collecting immature seed may cause phenotyping of seed properties to be hampered.

Conclusion

In the face of a changing environment, the plant research community has yet to reach the volume and speed of plant improvement required to effectively feed a growing global population. The combination of developing genomics capabilities with rapid gene fixation procedures has the potential to dramatically increase the rate of genetic gain in breeding programmers. SB has advanced the breeding plans of several economically important species since its introduction. Relying on light and temperature management, together with physical containment, SB effects several phases of plant breeding by hastening the breeding cycle. SB allows for quick

homozygozity and evaluation of lines that have previously been generated or altered, such as gene-edited crops and transgenic crops. SB approaches also make genotyping and phenotyping more resource-efficient; nevertheless, more research is needed to determine and minimize the negative impacts of SB conditions on plant growth and development. SB protocols are now accessible for small- or large-scale deployment, as well as further customizations based on local needs and innovations. As a result, the SB methods can be gradually enhanced and integrated with modern breeding approaches to fulfill their full potential for identifying and transferring genes important for crop resilience and adaptation. To foster the integration of SB systems in basic and practical research, particularly in developing countries, collaborative international partnerships including multi-disciplinary teams are required.

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