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Speed Breeding: Revolutionizing the Crop Improvement

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Abstract

Feeding our growing population is one of the primary concerns of plant breeders. Plant breeding needs to deliver modern cultivars in a time- and resource-efficient manner. Speed breeding techniques allow breeders to advance crop generation in a shorter period of time. The plants are grown in controlled growth chambers or greenhouses using optimal light intensity and quality, particular day length and temperature, which accelerates various physiological processes in plants. Speed breeding could serve as a basic platform for integrating high-throughput phenotyping and genotyping techniques, marker-assisted/genomic selections, and gene editing for the improvement of the traits in crop species.

1. Introduction

The extended duration of the breeding cycle poses a significant challenge in plant breeding programs, particularly those focused on line development. Following the selection and inter-mating of parents requires 4 to 6 generations to produce genetically stable homozygous lines suitable for field assessment. The time required to identify suitable parent plants for the subsequent breeding cycle directly influences the pace of genetic improvement and the duration needed to introduce enhanced cultivars in the farmer's field. Crop improvement techniques have evolved over the years, with one of the most promising and cutting-edge approaches being "speed breeding". This revolutionary method is transforming the way we cultivate crops and holds the key to ensure global food security (Bhatta et al., 2021).

2. The Need for Speed Breeding

As the global population is accelerating, it is estimated that we will need to produce more food by 2050 to adequately feed everyone. This is a daunting task, especially when faced with the unpredictability of climate change, which affects crop yields and makes traditional farming methods less reliable.

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3. How it Works

Speed breeding, is a technique that combines science, technology, and innovation to accelerate the breeding process and develop hardier, higher-yielding crops faster than ever before (Li et al., 2018). Speed breeding leverages the natural growth cycle of plants and enhances it through controlled environments and advanced technologies. At its core, this method involves manipulating the conditions in which plants grow to accelerate their life cycle. Traditional breeding can take years, to produce new crop varieties. However, speed breeding can reduce this time to few years (Figure 1). The process of speed breeding is done by growing the crops under

➢ Controlled Environments: Speed breeding takes place in specialized growth chambers or greenhouses, where environmental factors like light, temperature, humidity, and carbon dioxide levels are meticulously controlled to optimize plant growth.

➢ Extended Light Exposure: One of the key factors is providing plants with extended light exposure. By using specialized LED lights, researchers can mimic long summer days, encouraging rapid growth and early flowering.

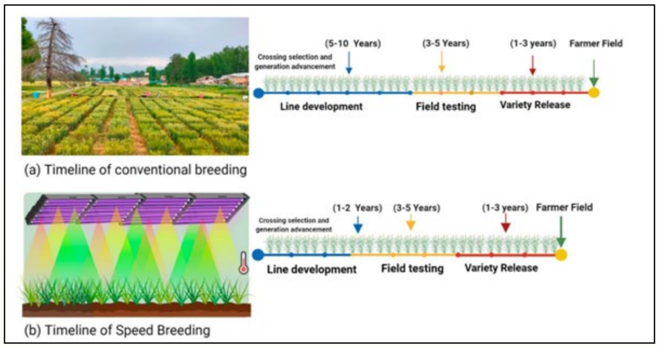

Figure 1: Comparison of Conventional and Speed Breeding Approaches (Bhargava et al., 2023)

4. Applications of Speed Breeding for Crop Improvement

4.1. Integrated Phenotyping with Speed Breeding as a Tool for Improving Yield

Phenotyping serves as the initial step in any breeding selection method. By combining phenotyping and speed breeding, a multi-purpose approach was used to boost yield. Population development of more than 1000 recombinant inbred lines of wheat was advanced to 6 generations within 18 months using speed breeding technique (Christopher et al., 2015).

Gene editing in combination with speed breeding for crop improvement

While traditional breeding methodologies have undoubtedly achieved success in improving crops, they have inadvertently led to a reduction in genetic diversity due to persistent selection and domestication practices. The continuous pursuit of specific desirable traits has resulted in a narrowing of the gene pool. In contrast, emerging technologies such as genome editing, exemplified by the CRISPR/Cas system, offer a more targeted and precise approach to genetic modification. By manipulating specific genes, CRISPR/Cas has the potential to significantly enhance crop yields. One notable advantage of CRISPR/Cas technology is its ability to introduce diverse genetic changes at multiple loci. This versatility addresses the limitations associated with decreased genetic variation in traditional breeding.

To overcome the limitations of both traditional breeding and genome editing in isolation, there is a growing interest in combining these approaches with speed breeding techniques. Speed breeding accelerates the plant breeding cycle, enabling the cultivation of multiple generations in a single year. This integration not only provides a solution to the time and effort constraints associated with genome editing but also offers the potential to rapidly introduce and select for beneficial traits, creating a more efficient and responsive breeding process (Wolter et al., 2019).

4.2. Boosting Genetic Gain by Speed Breeding and Genomic Selection

Accelerating breeding cycles and minimizing the number of cycles required for novel crop varieties is essential for swift advancements in breeding and research. The integration of genomic selection with speed breeding techniques, which manipulate environmental factors like light and temperature to hasten plant growth, can amplify the positive effects on genetic gain. The synergy between speed breeding and genomic selection not only enhances genetic gain, but also holds the promise of expediting the breeding process for a variety of crops by facilitating quicker turnover of generations. This combined approach contributes to a more efficient and rapid evolution of crop varieties (Jighly et al., 2019).

4.3. Speed Breeding to Accelerate Domestication

Plant domestication, the transformation of wild plants

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into crops, involves hybridization and selective breeding, especially in polyploid crops. This process is time-consuming. To expedite it, speed breeding is integrated, reducing both the time and generations needed. Evidence of plant domestication in polyploid plants like peanuts and bananas has emerged, combined with rapid breeding (Hickey et al., 2019). In comparison to the regular breeding phase, it reduces the time it takes to produce multiple generations in a shorter period.

4.4. Multiple Disease Resistance by Speed Breeding

Plant breeders are adopting innovative methods to enhance crop quality and adapt to shifting climates and diseases. For example, Hickey et al. (2017), introgressed disease resistance in the two-row barley cultivar Scarlett, using novel approaches for rapid trait introduction. The researchers used four donor lines combining multiple disease resistance (i.e. leaf rust, net and spot forms of net blotch and spot blotch) and transferred disease resistance into Scarlett using a modified backcross strategy, incorporating both multi-trait phenotypic screens and the rapid generation advance technology speed breeding. The F1 plants were grown under speed breeding conditions to effectively accelerate plant development and finally 87 $BC_1F_{3:4}$ introgression lines (ILs) were developed in just two years. These ILs displayed high levels of multiple disease resistance and it is proposed that, speed breeding approach could be useful to rapidly transfer genes for multiple target traits into adapted cultivars or pyramiding of desirable traits into elite breeding material.

5. Challenges and Future Prospects

The use of speed breeding techniques is a valuable approach to accelerate conventional breeding programs. However, the technology requires expertise, effective and complementary plant phenomics facilities, appropriate infrastructure, and continuous financial support for research and development. However, the most common challenges hampering the use of speed breeding include (a) access to suitable facilities, (b) staff trained in the protocol, (c) adopting major changes to breeding program design and operations, and (d) the need for long-term funding (Wanga et al., 2021).

6. Conclusion

The plant research community has yet to achieve the scale and speed of plant improvement required to effectively feed a burgeoning population. Speed breeding has accelerated the breeding programs of many economically important crop species. It enables rapid progression to homozygosity and evaluation of already developed or transformed lines, viz., gene-edited crops and transgenic crops. It also facilitate resource-efficient genotyping and phenotyping, however, further research is required to assess and mitigate it's negative effects.

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