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Speed Breeding: A Novel Technique to Accelerate Crop Life Cycle and Food Security

Arnab Mandal^{1*}, Animesh Jana¹, Debashrita Giri¹

Department of Genetics and Plant Breeding, Midnapore City College, Kuturiya, Bhadutala, Paschim Midnapore, West Bengal, India¹

ABSTRACT: Fast changing environment, pathogen pressure, and population growth are becoming alarming issues for modern agriculture. The world's scientists are now extremely concerned about the urgency of improve crops. Conventional breeding methods take a long time to stabilize the variability within the population. To overcome this challenge, speed breeding offers a revolutionary opportunity for crop improvement. Speed breeding, a method of advancing generations rapidly by minimizing the generation cycle through manipulating temperature, light duration and intensity, soil moisture, PGRs, and photoperiod duration. Speed breeding has been successfully applied to a variety of crops, including cereals, pulses, and canola crops, yielding 4-6 generations every year. Speed breeding has emerged as a powerful and effective technique for creating novel plant kinds quickly and requires less work than breeding techniques. Genetic selection along with speed breeding can speed up the breeding cycle, even allowing more genetic improvement. Improvement of climate-resilient crop genetically through genomic selection, advance genome tools, and speed breeding methods helps to get an efficient result earlier than the conventional breeding approaches. Overall, speed breeding is a viable and innovative technique for crop improvement that will undoubtedly support the world's agricultural needs and minimize the impact of climate change on agriculture. An overview of Speed breeding techniques on several crops and their importance in the present crop improvement landscape is given in this review.

KEYWORDS: Speed breeding, Photoperiod, Generation cycle, Controlled environment, Genomic selection

I. INTRODUCTION

The world's population is growing proportionally by at least 25%, but the changing climate, land degradation and various natural phenomena did not meet the world's high food demand. High demand cannot be fulfilled by the traditional and conventional breeding procedures, so breeders need to develop new crop varieties that can fulfill the food demand for future generations. Crop generation time and environmental factors make hindrances to the breeding years. Speed breeding is one of those techniques in which environmental conditions (e.g., light, temperature, humidity, etc.) can be easily controlled and accelerate the growth and development of crops rapidly from vegetative stage to reproductive stage through high-density planting (Pasala et al., 2024). The concept of speed breeding first came 150 years ago when a botanist saw the growth of plants under artificial light. US NASA initially started the speed breeding approach to raise the wheat variety "USU-Apogee" in space, utilizing prolonged photoperiods or steady light and exact temperature to accelerate photosynthesis and enhance plant development. The first implementation of NASA's speed breeding techniques on wheat and peanut production was demonstrated by Dr. Lee Hickey and his colleagues at the University of Queensland, John Innes Centre, and the University of Sydney in Australia in 2003. Traditional plant breeding techniques involve deliberate crossing and subsequent selection of a desired plant type, which takes a significant amount of time (often 8–10 years) and labour. Speed breeding decreases the germination time by the proper utilization of light and temperature and increasing the biomass and seed production in long-day crops like rice, wheat, lettuce, etc. The speed breeding technology, along with these artificial conditions, reduces the crop generation time much less than normal glasshouse conditions.

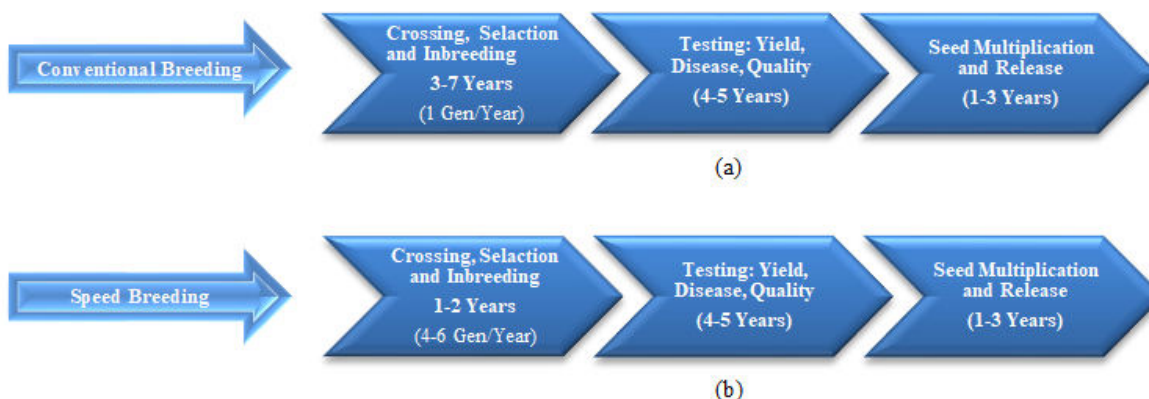


Fig. 1. Timeline of (a) Conventional Breeding (b) Speed Breeding

II. METHODS OF SPEED BREEDING

Photoperiod, temperature, light quality and intensity, and planting density all have an impact on crop growth and development. Knowledge of fundamental crop growth and development processes is required to build and optimize speed breeding protocols for a specific species. In many plants, photoreceptors detect changes in photoperiod and can initiate the reproductive development process. This improves reproductive success by timing plant development with seasonal changes in the environment. Short-day plants (SDPs) require a longer than necessary night length, while long-day plants (LDPs) require a shorter night length and day-neutral plants (DNPs) are not affected by night length. SB promotes flowering by shortening the night period for LDPs and DNPs while lengthening the night period for SDPs. To improve SB procedure, higher temperatures can be employed to enhance vegetative development while lower temperatures are maintained during reproductive growth. Light is a vital component for plant development, and both intensity and quality are significant. Increasing light intensity in SB facilities may boost photosynthetic rate and reduce days to flowering. Sensors that automatically modulate light levels may be utilized in SB facilities with a combination of natural and supplemental lighting systems to maintain ideal light intensity for photosynthesis. In large-scale SB operations, optimizing plant density is crucial to increasing efficiency. The days to flowering are accelerated in barley and wheat by high-density plantings. In many plants, competition for resources causes stress, which leads to flowering. Due to the negative effects of high-density competition on plant health, increasing density comes at the expense of seed set and flowering time (Bhatta et al., 2021). There are three types of speed breeding techniques that are,

- **Speed Breeding-Environment controlled chamber speed breeding:**

Controlled environment with a temperature of 22°C with a 22-hour photoperiod and 17°C during a dark period of 2 hours. Temperature and light up and down for 1 hour 30 minutes to mimic dusk and dawn conditions normally. Humidity should be 70%. For maintaining 370-380 $\mu\text{mol m}^{-2} \text{s}^{-1}$ light intensity, need metal halide quartz iodide lamps, white LED bars, and far-red LED bars. This technique has been used for crop improvement in wheat and barley (Chaudhary and Sandhu, 2024).

- **Speed breeding II-Glass house speed breeding:**

22-hour photoperiod with a 2-hour turnover in a temperature-controlled glasshouse and preinstalled high-pressure sodium vapour light. Temperature should be 22°C in photoperiod and 17°C in dark condition. 2-hour period with no lamp and 17°C cycle occurred during night. Light intensity of 440-650 $\mu\text{mol m}^{-2} \text{s}^{-1}$ is needed for adult plant height. This technique has been used for crop improvement in wheat, chickpea, barley, and canola (Ghosh et al., 2018).

- **Speed breeding III- Homemade growth room design for low-cost speed breeding:**

The room size should be 3m× 3m× 3m with insulated sandwich panelling with 7-8 LEDs and a 1.5hp inverter for air conditioner. 12 hrs.-12 hrs. (Light-Dark) for four weeks and then 18 hrs.-6 hrs. The light quantity for photosynthetically active radiation (PAR) at bench height must be ranged from 210-600 $\mu\text{mol m}^{-2} \text{s}^{-1}$ and 340-590 $\mu\text{mol m}^{-2} \text{s}^{-1}$ for adult plant height. This technique has been used for the crops like triticale, oat and barley (Chaudhary and Sandhu, 2024).

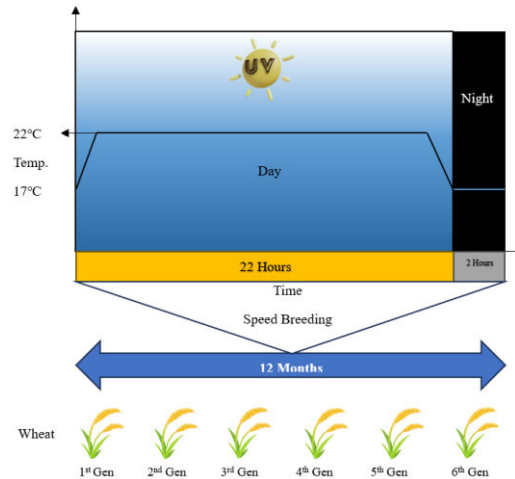


Fig. 2. Acceleration of life cycle (4-6 generations) by controlling light, photoperiods, and temperature

III. ROLE OF SPEED BREEDING IN CROP IMPROVEMENT

- **Speed breeding to accelerate artificial selection**

Plant domestication is the process of transforming wild relatives into crop plants through artificial selection. Speed breeding is very potential tool for crop domestication. Speed breeding can help breeders to choose valuable traits to improve old crop variety. Plant breeding is specially connected with polyploidy crops, which is a time-consuming process; speed breeding integrated with it and decreases the time duration and number of generations of that crop. Plant domestication needs to be proof polyploidy in groundnut and banana (Begna, 2022). Breeders used speed breeding in *Triticum dicoccoides* (wild emmer wheat) to accelerate the domestication. Speed breeding applied to create crops that can better stand with environmental stresses, viz. drought, heat, salinity etc. In *Arabidopsis thaliana*, speed breeding techniques are used to develop drought resistant varieties in just a few generations (Wani et al., 2020).

- **Horizontal resistance by Speed Breeding**

Traditional breeding methods are affective and time-consuming, need many seasons for planting and harvesting. By the use of speed breeding researchers select for desirable traits such as disease tolerance, which is very critical for desirable crop yield and food security. Particularly this is for those regions where disease plays a significant role in agriculture. In wheat, multiple disease resistance is very desirable because wheat is very much susceptible to wild range fungal diseases such as Rust (*Puccinia* spp.), Wilt (*Fusarium* spp.). By using speed breeding technique breeders have been able to incorporate several rust resistant genes into a single variety. The speed breeding allows for rapid testing for gene combinations, making it easier for select broad spectrum resistance (Jamil et al., 2020). Speed breeding is not limited in wheat but also applied to other major crops like rice, barley, and other legumes. By using speed breeding rice breeders can easily test the combinations of resistance genes (Samantara et al., 2022). A novel method applied in the European popular barley variety Scarlett. Development of 87 BC1F3:4 Scarlett introgression lines (ILs) within two years using a modified backcross strategy that combined four donor lines with multiple disease resistance through multi-trait phenotypic screening and speed breeding (Hickey et al., 2017).

- **Genomic selection and genetic gain by speed breeding**

Genetic gain means the improvement of desirable traits in a population over many generations. Achieving genetic gain is a difficult process due to long breeding cycles. Breeding techniques including genetic engineering, genomic selection, and double-haploid technology have improved genetic gain rates and reduced breeding cycles in crops like maize, rice, and wheat. These methods can have an even greater impact when combined with speed breeding techniques, which enable fast generation advancement by increasing the growth and development of plant populations under controlled photoperiod and temperature (Hickey et al., 2017). Genomic selection is a process molecular marker to predict the genetic potential present in the DNA of an individual. Rather than phenotypic data collection over several generations, genomic selection helps breeders to select the desirable traits early in their life cycle, based on their genetic makeup

(Desta and Ortiz, 2014). Because of the low dependence on the phenotypic traits the effect of environmental selection is low. In crops like maize, wheat and soybean genomic selection have shown significantly improvement in breeding value predictions and improvement of complex traits, such as disease resistance, high yield etc (Jannink et al., 2010).

• **High throughput phenotyping with speed breeding**

All breeding selection methods begin with phenotyping. Modern plant phenotyping, on the other hand, examines complicated traits linked to growth, yield, and stress adaptation with better accuracy and precision across a wide range of organizational sizes, from organs to canopy. A more recent and comprehensive definition of plant phenotyping includes the evaluation of complex plant traits such as growth, development, tolerance, resistance, architecture, physiology, ecology, and yield, as well as the basic measurement of individual quantitative parameters that serve as the foundation for complex trait assessment (Begna, 2022). Plant biomass, root morphology, leaf characteristics, and fruit qualities are all examples of structural and functional properties that may be directly measured. High-throughput phenotyping (HTP) is a non-destructive and quick method for monitoring and assessing various phenotypic variables associated with growth, production, and adaptability to biotic or abiotic stressors (Pabuayon et al., 2019). The integration of phenotyping with speed breeding enhances the efficiency of the breeding process. Speed breeding accelerates the speed of genetic evaluation, while phenotyping ensures the correct traits and their evaluation. These tools help breeders to select high yielding traits.

• **Crop improvement through genome editing and speed breeding**

Although conventional plant breeding has been effective in developing outstanding crop types, genetic quality has declined in the modern era as a result of continuous selection and long-term crop domestication, which is one of the limiting factors to crop quality advancement. In this day, genome editing technology has proven to be useful. Gene editing is a process that includes changing a crop species’ genes to increase production. The CRISPR/Cas system expands the potential for genomic variety. It has multiplexing capabilities, which means it can modify the number of target genes at the same time. It solves the real issue, and a high-yielding variety may be generated, but this method takes a long time and demands a lot of work; hence, combining genome editing with speed breeding has the positive future to overcome these problems and 4-6 generations can be produced in a single year (Begna, 2022).



Fig. 3. Relations between speed breeding and other modern breeding techniques

IV. ACHIEVEMENTS

1. This technique is responsible for the development of the "DS Faraday" wheat variety, which is a high protein, milling wheat with tolerance to pre-harvest sprouting (Shivakumar et al., 2018).
2. Scarlett is the most extensively cultivated cultivar of barley in Argentina, which is susceptible to many diseases. Within two years, resistant lines were created by selecting four lines and using a modified backcrossing procedure (Hickey et al., 2017).
3. Using speed breeding, a salt-tolerant rice variety 'YNU31-2-4' was created. Speed breeding outperforms "Shuttle Breeding" and generates three times as many generations (Haroon et al., 2020).
4. Speed breeding proves useful in assessing the loss of function of a specific locus across different generations, as demonstrated in the F6 recombinant inbred line of Paragon x W352 under speed breeding conditions, focusing on the FLOWERING LOCUS T-B1 (Shinde et al., 2023).
5. Speed breeding can accelerate the identification and use of allelic diversity in landraces and wild relatives of crops. Screening the Vavilov wheat collection for leaf rust resistance using speed breeding, combined with DNA markers linked to known genes, led to the identification of new sources of resistance (Riaz et al., 2018).

V. LIMITATIONS OF SPEED BREEDING

Some major limitations of Speed breeding technology are:

1. **Resources:** Advanced control environment resources like growth chamber, temperature, and light controlling sensors increase the expense for this modern technology in speeding up species generation cycle. Furthermore, speed breeding remains a challenge in countries with few resources due to inadequate infrastructure, insufficient knowledge and limited engagement with international organizations (Samantara et al., 2022).
2. **Genetic loss:** Speed breeding causes rigorous growth and that can result in limited seed yield and genotypic variations in crops. These variations may have an impact on crop stability and uniformity, raising questions regarding crop performance consistency across different environments. Difficult management and growing plants beyond their physiological limitations can be detrimental and cause genetic loss. The early harvest of immature seeds before they have finished their natural ripening phase interferes with the phenotyping of several traits (Potts et al., 2023).
3. **Standardization:** Speed breeding in short-day and day-neutral plants need species and variety-specific uniformity. The changes in photoperiodic conditions between short-day and long-day plants range from minutes to hours, making SB standardization challenging. Because of the different responses of plant species to photoperiodic circumstances, there is no uniform speed breeding procedure. Certain crops may be harmed by prolonged photoperiods. Plant growth can be slowed down and stress hormone levels raised by an excessive photoperiod. Flowering in rice, soybean, and amaranth treated with 10-hour photoperiods using blue-enriched and far-red-deprived light did not affect soybean flowering, but in certain rice and amaranth genotypes, flowering duration was shortened by 10 and 20 days, respectively (Jähne et al., 2020).
4. **Skilled Labour:** A major issue in speed breeding is the lack of workers with the necessary qualifications, as well as possibilities for ongoing professional growth and training. In the public sector, SB is hampered by labour turnover, insufficient legal and administrative frameworks, and a shortage of qualified plant breeders and technicians in poor countries. Investments in plant breeding education, research, and staff retention are necessary for developing countries to sustain long-term crop improvement initiatives and scientific breakthroughs (Sharma et al., 2022).

VI. CONCLUSION

Speed breeding is a technique that helps to achieve solutions regarding climate change and food security. By controlling temperature, light sensitivity, photoperiod, population density, and humidity, breeders can easily accelerate the seed-to-seed cycle in 4-6 generations per year without losing yield. Not only acceleration of generation but also speed breeding contributes to achieve major targets related to sustainability and food security. When modern breeding techniques like MAS, CRISPR gene editing, phenotyping, and genomic selection, combined with speed breeding technique, show much faster results in achieving desirable outcomes. Although use of speed breeding methods is expensive and requires certain facilities and skilled labour, it can significantly speed up conventional breeding procedures and provide stable, homozygous genotypes more quickly. Many crops like wheat, barley, chickpea, and

canola shows a positive impact on faster yield improvement, stress resistance, genomic selection, and genetic gain through cutting-edge technology i.e. speed breeding. As the need for food rises, SB's role in speeding genetic improvement and promoting resilient agricultural systems will be essential in influencing agriculture's future. Platforms that promote international cooperation, capacity building, and responsible governance have the potential to stimulate widespread use of this innovative method. In a developing country like India, where assets are severely limited and food shortages are increasing due to population growth, speed breeding might be one of the most viable options for shortening the reproduction cycle and speeding up the screening process.

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