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Speed Breeding and Its Implications in Crop Improvement

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Speed breeding is an innovative approach in modern plant breeding that aims to accelerate the crop improvement process by significantly reducing the generation time. The increasing demand for food due to rapid population growth, climate change, shrinking arable land, and emerging biotic and abiotic stresses has necessitated the development of faster breeding strategies. Conventional breeding methods often require 8–15 years to develop a new variety, which limits the pace of genetic gain. Speed breeding overcomes this limitation by manipulating environmental conditions such as photoperiod, temperature, and light intensity to promote rapid growth, early flowering, and quick seed production. Using this technique, multiple generations can be achieved within a single year, allowing breeders to accelerate selection and fixation of desirable traits. Speed breeding has been successfully applied in crops such as wheat, barley, chickpea, canola, and peanut. When combined with modern molecular breeding tools, speed breeding offers immense potential to enhance crop productivity and ensure global food security.

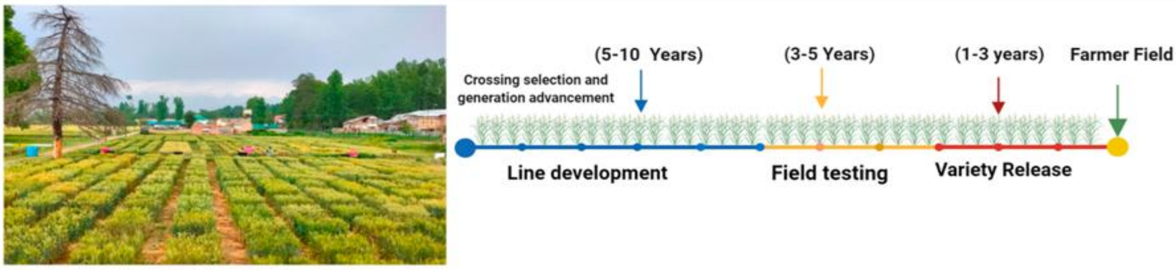
Keywords: Speed breeding, rapid generation advancement, photoperiod, crop improvement, controlled environment.

Introduction

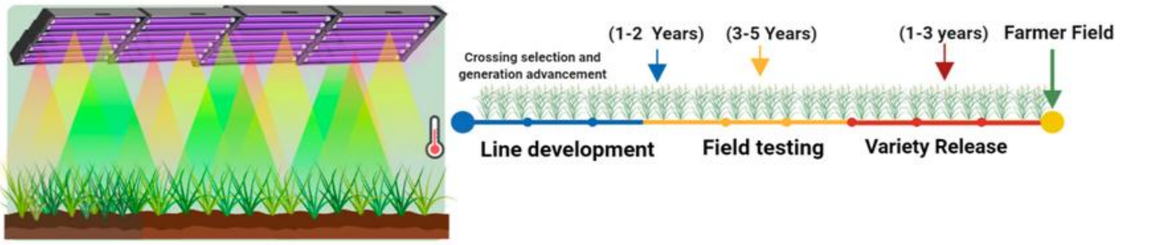
Agriculture today faces enormous challenges due to climate change, population explosion, limited natural resources, and increasing incidence of pests and diseases. To sustain food production and meet future demands, it is essential to develop high-yielding, stress-tolerant crop varieties at a much faster rate. Traditional plant breeding approaches are effective but time-consuming, often requiring several years to complete a breeding cycle. This long duration hampers rapid genetic improvement and delays the release of superior varieties to farmers. Speed breeding has emerged as a revolutionary technique to shorten the breeding cycle and enhance genetic gain. By extending the photoperiod and optimizing environmental conditions, speed breeding enables plants to complete their life cycle in a significantly shorter time. This technique has gained global attention due to its effectiveness, flexibility, and compatibility with modern breeding technologies.

Concept of Speed Breeding

Speed breeding refers to the practice of accelerating plant growth and development by manipulating environmental factors under controlled conditions. The most critical factor in speed breeding is the extension of photoperiod, often up to 22 hours of light per day, which enhances photosynthesis and promotes early flowering. In addition to light duration, factors such as temperature, humidity, light intensity, and nutrient management are carefully regulated. Another important component of speed breeding is the harvesting of immature seeds. Seeds are collected before full physiological maturity and subjected to rapid drying and rehydration to enable quick germination. This practice further reduces the seed-to-seed cycle and allows breeders to advance generations rapidly.

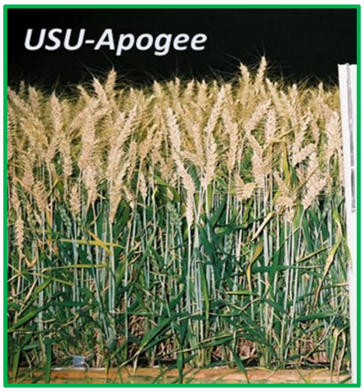


(a) Timeline of conventional breeding



(b) Timeline of Speed Breeding

History and Development of Speed Breeding



The concept of rapid generation advancement dates back to experiments conducted by NASA and Utah State University in the 1990s to study wheat growth in space. These efforts led to the development of rapid cycling wheat varieties such as 'USU-Apogee'. Later, researchers in Australia refined the approach by optimizing photoperiod and temperature conditions. The term "Speed Breeding" was popularized by scientists at the University of Queensland and the University of Sydney. Landmark studies by Watson et al. (2018) demonstrated the feasibility of achieving up to six generations per year in crops like wheat and barley. Since then, speed breeding has been widely adopted in research institutions and commercial breeding programs worldwide.

Drivers of "SPEED BREEDING " vehicle

Methods of Speed Breeding

Speed breeding can be implemented using different infrastructure setups depending on available resources.

Controlled Environment Chamber

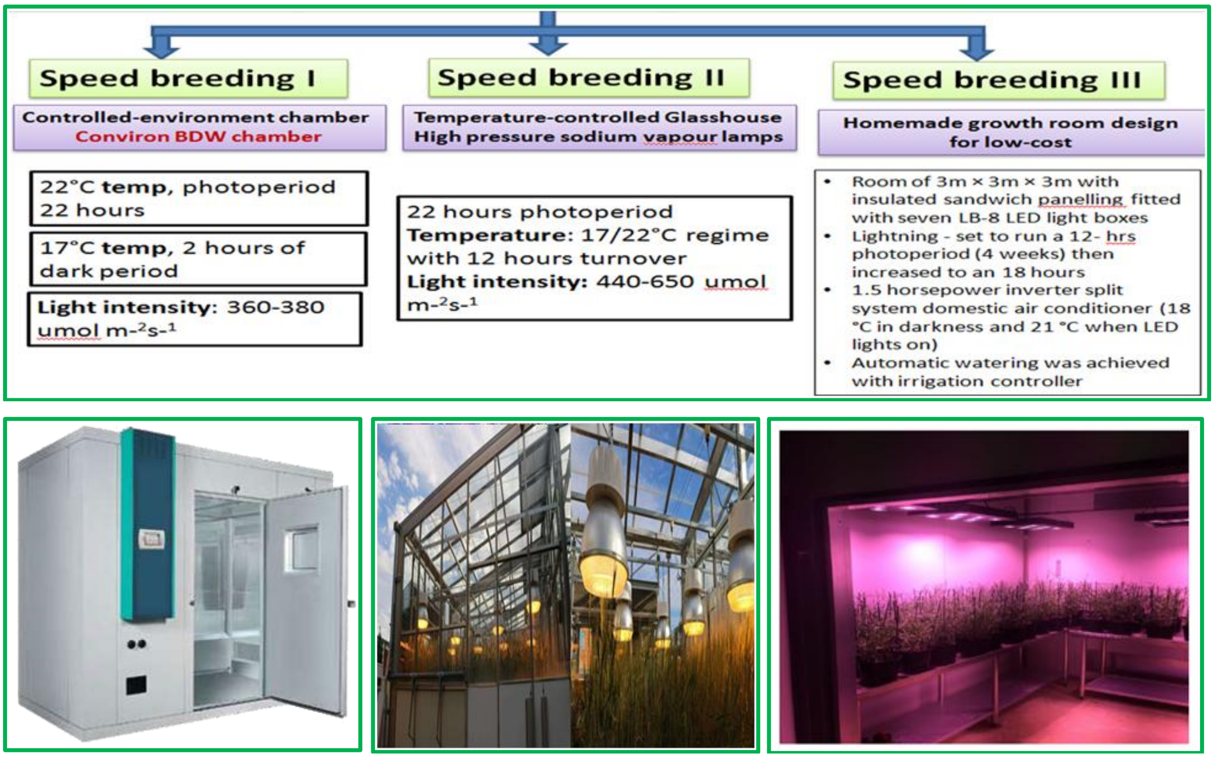
Growth chambers provide precise control over environmental conditions. Plants are exposed to 22 hours of light and 2 hours of darkness, with temperatures maintained at approximately 22°C during the light period and 17°C during the dark period. Relative humidity is kept around 70 percent.

Glasshouse Speed Breeding

Glasshouse-based speed breeding uses supplementary lighting such as high-pressure sodium or LED lamps to extend the photoperiod. This method is suitable for large-scale breeding programs and allows better simulation of natural conditions.

Low-Cost Speed Breeding

Low-cost growth rooms equipped with LED lights and domestic air conditioners offer an economical alternative for developing countries. Although environmental control is less precise, this approach still enables rapid generation advancement.



Applications of Speed Breeding

Speed breeding has been successfully applied in several major crops. In wheat and barley, flowering can occur within 35–40 days after sowing, allowing up to six generations per year. In chickpea, rapid generation advancement has enabled faster development of disease-resistant lines. In peanut, speed breeding has been integrated into commercial breeding programs to reduce varietal development time.

Examples of SB in different crops

Crop	Goal	Generation per year	Approach utilized	Reference
Spring wheat	Resistance to stem rust, stripe rust and yellow spot	4–6	Extending light exposure through supplemental light with SSD	(Ghosh et al., 2018; Riaz et al., 2016)
Durum wheat	Resistance to crown rot	6	SB with multi-trait phenotyping	(Alahmad et al., 2018)
Barley	Resistance to leaf rust	4–6	Extending light exposure through supplemental light with SSD	(Hickey et al., 2017)
Pea	Rapid generation advance	2–3	Extending light exposure through supplemental light with SSD	(O'Connor et al., 2013)
Chickpea	Rapid generation advance	4–6	Rapid generation advance	(Samineni et al., 2019)
Radish	Rapid generation advance	NA	Extending light exposure through supplemental light with SSD	(Ghosh et al., 2018)
Alfalfa	Rapid generation advance	NA	Extending light exposure through supplemental light with SSD	(Ghosh et al., 2018)
Canola	Pod shattering	4–6	Extending light exposure through supplemental light with SSD	(Watson et al., 2018)
Flax	Rapid generation advance	NA	Extending light exposure through supplemental light with SSD	(Watson et al., 2018)
Arabidopsis	Rapid generation advance	NA	Extending light exposure through supplemental light with SSD	(Watson et al., 2018)
Apple	Fire blight resistance	1	Early flowering induction and MAS	(Flachowsky et al., 2011)
Rose	Rapid generation advance	NA	Extending light exposure through supplemental light with SSD	(Ghosh et al., 2018)
Lentil	Rapid generation advance	8	Early flowering induced by phytohormone	(Mobini et al., 2015)
Faba bean	Rapid generation advance	7	Early flowering induced by phytohormone	(Mobini et al., 2015)
Lupin	Rapid generation advance	5	Early flowering and in vitro germination of immature seeds	(Croser et al., 2016)
Clover	Rapid generation advance	2.7–6.1	In vitro-assisted single-seed descent method	(PazosNavarro et al., 2017)
Amaranth	Rapid generation advance	6	Extending light exposure through supplemental light up to vegetative growth then short-day exposure for flowering	(Stetter et al., 2016)
Soybean	Rapid generation advance	5	Extending light exposure through Supplemental light and LED lighting under SB for short –day plant	(Jähne et al., 2020)

Integration with Modern Breeding Tools

Speed breeding can be effectively combined with marker-assisted selection, genomic selection, and genome editing technologies. This integration allows early generation selection for target traits and accelerates the development of elite cultivars.

Advantages of Speed Breeding

Speed breeding offers numerous advantages, including reduced breeding cycle time, faster attainment of homozygosity, increased selection efficiency, and year-round breeding. It also facilitates rapid trait pyramiding and enhances research productivity.

Limitations of Speed Breeding

Despite its advantages, speed breeding has certain limitations. High initial infrastructure costs, increased energy consumption, and crop-specific responses to extended photoperiods are major challenges. Additionally, evaluation of complex traits such as yield may require field validation.

Conclusion and Future Prospects

Speed breeding represents a major advancement in plant breeding, offering a practical solution to accelerate crop improvement. Future developments in energy-efficient lighting and controlled environment technologies are expected to further enhance its adoption. Integration of speed breeding with genomic tools will play a crucial role in developing climate-resilient and high-yielding crop varieties.

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