



Speed Breeding in Vegetable Crops

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Speed breeding is emerging as a transformative approach in modern plant breeding, particularly for accelerating crop improvement programs. It refers to a rapid generation advancement technique designed to significantly reduce the duration of the crop life cycle. By optimizing growth conditions, this method enables the production of up to six generations per year in photo-insensitive crops, while two to three generations can be achieved in photo-sensitive species. The technique operates by precisely regulating photoperiod, temperature and humidity within controlled environments such as greenhouses and polyhouses, thereby creating ideal growth conditions.

Speed breeding not only shortens breeding timelines but also enhances the efficiency of developing improved crop varieties. It is often integrated with advanced technologies such as high-throughput genotyping and genome editing tools, including CRISPR, to further accelerate genetic gains. Originally conceptualized by NASA to facilitate rapid food production in space, this approach has since been adapted for agricultural applications.

The primary focus of speed breeding is the manipulation of environmental parameters like light intensity, photoperiod, temperature and humidity to promote rapid plant growth and early flowering. Its applications are diverse, including accelerated breeding cycles, enhancement of transgenic and genome editing pipelines, faster genomic selection and detailed studies of plant physiological traits. Overall, speed breeding represents a powerful strategy for developing improved crop varieties in a shorter time frame, thereby supporting sustainable agricultural production.

Keywords: Speed breeding, rapid generation advancement, controlled environment, plant breeding, genomic selection

Introduction

The increasing global population and changing environmental conditions have intensified concerns about food security, as current crop improvement rates are insufficient to meet future demands. Speed breeding has emerged as an advanced technique to overcome this challenge by significantly reducing the duration of conventional breeding cycles. Originally introduced by NASA in the 1980s for space-based crop production, this method accelerates plant growth by manipulating environmental factors such as photoperiod, temperature, and humidity under controlled conditions.

In contrast to conventional breeding, which typically requires 8–10 years to develop new varieties, speed breeding facilitates rapid generation advancement by enabling multiple generations per year through extended photoperiods, usually around 22 hours of light and 2 hours of darkness. This approach was initially implemented in crops such as pea (*Pisum sativum*), barley (*Hordeum vulgare*), wheat (*Triticum aestivum* and *Triticum durum*), chickpea (*Cicer arietinum*) and canola (*Brassica napus*). Importantly, plants developed under speed breeding conditions exhibit normal growth and development, maintain their ability to

be easily hybridized and produce seeds with high germination capacity, demonstrating the reliability and effectiveness of this technique in crop improvement programs.

Speed breeding

Speed breeding is a technique that involves extending the photoperiod and optimizing controlled growing conditions such as temperature, plant spacing and soil media within glasshouses or polyhouses to enable rapid generation advancement. By shortening the duration of the breeding cycle, it facilitates quicker development of successive generations. As a component of accelerated breeding, speed breeding enhances conventional breeding methods by significantly reducing the crop life cycle and improving the efficiency of crop improvement programs.

Tomato, a day-neutral crop, responds effectively to speed breeding strategies involving manipulation of light conditions. Studies using the “TOMSIM” simulation model have demonstrated that continuous light exposure (24 hours per day) can significantly enhance tomato productivity. A hypothetical genotype tolerant to continuous light conditions was predicted to produce 22–26% higher fruit yield compared to plants grown under an 18-hour photoperiod. Furthermore, by introgressing continuous light tolerance into modern F₁ hybrid lines, yield improvements of up to 20% can be achieved. These findings indicate that extended photoperiods play a crucial role in maximizing tomato yield under controlled environments.

In addition to tomato, speed breeding approaches are also applied in other vegetable crops. For instance, the use of doubled haploidy techniques in cauliflower (*Brassica oleracea* var. *botrytis* L.) has proven effective in accelerating crop improvement by rapidly developing homozygous lines, thereby enhancing breeding efficiency and reducing the time required for cultivar development.

General Setup for Speed Breeding

1. **Light:** Provide light within the photosynthetically active radiation (PAR) range of 400–700 nm. The use of LED-based environmental lighting systems is recommended to ensure efficient and uniform light distribution for optimal plant growth.
2. **Photoperiod:** Maintain an extended photoperiod of approximately 22 hours of light followed by 2 hours of darkness. This regulated light–dark cycle promotes rapid plant growth and accelerates developmental processes.
3. **Temperature:** Keep the temperature around 22°C during the light phase and reduce it to about 17°C during the dark period. Such controlled temperature conditions support faster growth and effective progression of the breeding cycle.
4. **Humidity:** Maintain relative humidity levels between 60–70% to create a favorable microenvironment, reduce plant stress, and ensure efficient physiological functioning during rapid growth.

Equipment Setup for Speed Breeding

- **Hardware**
- **Cabinet Structure:** A well-designed enclosed or semi-enclosed growth chamber or cabinet to maintain controlled environmental conditions.
- **Lighting System:** Installation of efficient lighting sources, preferably LED systems, to provide optimal light intensity and photoperiod regulation.
- **Temperature and Humidity Control System:** Devices and sensors to monitor and maintain precise temperature and relative humidity levels for ideal plant growth.
- **Software Installation and Setup:** Integration of automated control systems and software to regulate environmental parameters such as light, temperature, and humidity for consistent and efficient operation.

Different Types of Speed Breeding Setups

Speed Breeding I – Controlled Environment Chamber: This setup utilizes a controlled growth chamber such as the Conviron BDW. Temperature is maintained at approximately

22°C during the light period and reduced to 17°C during the 2-hour dark phase, with relative humidity around 70%. The lighting system consists of a combination of far-red LEDs, white LED bars and ceramic metal halide lamps, providing a light intensity of about 360–380 $\mu\text{mol m}^{-2} \text{s}^{-1}$ to support rapid plant growth.

Speed Breeding II – Glasshouse Conditions: In this method, a temperature-controlled glasshouse is equipped with high-pressure sodium vapor lamps to maintain an extended 22-hour photoperiod. Temperature is regulated between 17°C and 22°C, while light intensity ranges from 440–650 $\mu\text{mol m}^{-2} \text{s}^{-1}$. A 2-hour dark period is maintained at 17°C to ensure proper physiological functioning.

Speed Breeding III – Low-Cost Growth Room Setup: This approach involves a cost-effective growth room (approximately 3 × 3 × 3 m) constructed with insulated panels. Lighting is provided using LED light boxes, initially set to a 12-hour photoperiod and later extended to 18 hours. Temperature is maintained at 21°C during light periods and 18°C in darkness using an air conditioning system, along with automated irrigation for efficient water management.

Procedure of Speed Breeding

- A cost-effective speed breeding protocol can be implemented using a homemade growth room as an alternative to specialized chambers like the Conviron BDW. The setup typically involves an insulated room fitted with LED light boxes (approximately one per 0.65 m²) and supported by a 1.5 HP inverter split air conditioner for environmental control. Light intensity should be maintained within the PAR range of 210–260 $\mu\text{mol m}^{-2} \text{s}^{-1}$ at bench height and 340–590 $\mu\text{mol m}^{-2} \text{s}^{-1}$ at about 50 cm above the pots, with lights positioned around 140 cm above the bench. The system can accommodate around 90 pots of 20.3 cm size.
- Automated irrigation is achieved through controllers equipped with solenoid valves and individual drippers for each pot, while ambient humidity conditions are generally sufficient. Lighting should be enriched with red, blue and far-red wavelengths, initially set to a 12-hour photoperiod for four weeks and gradually extended to 18 hours. Temperature is maintained at approximately 21°C during light periods and lowered during darkness.
- The technique is commonly combined with the single seed descent method to accelerate generation turnover. Increased planting density allows rapid cycling of multiple lines, with plants reaching flowering nearly twice as fast as under conventional glasshouse conditions. This protocol has been successfully applied in crops such as wheat, barley, oat and triticale

Comparison with Other Approaches

- **Shuttle Breeding:** This method allows the cultivation of two generations per year by growing crops in different locations or seasons, whereas speed breeding enables the production of several generations annually under controlled environmental conditions, making it significantly faster.
- **Embryo Rescue:** Unlike embryo rescue, speed breeding does not require the application of plant growth regulators or specialized laboratory procedures. It is less labour-intensive and can be carried out without advanced tissue culture facilities.
- **Doubled Haploidy:** Although doubled haploidy is effective for producing homozygous lines, it requires skilled expertise and involves high costs. It is also limited by a single round of meiosis, restricting recombination. Additionally, its success rate is often genotype-dependent and the process can be labour-intensive, especially for large populations due to the need for manual embryo extraction.

Applications of speed breeding

Amaranthus (*Amaranthus tricolor*): Speed breeding in amaranthus, a short-day crop, utilizes LED-based lighting systems to manipulate light quality and photoperiod. By

maintaining a 10-hour photoperiod and using blue light enriched with reduced far-red wavelengths, flowering can be induced within 35 days after sowing - approximately 10 days earlier than under normal conditions. This approach enables multiple generations per year without the need for tissue culture techniques such as embryo rescue. Additionally, it can be integrated with multi-tier tray systems and genomic tools to enhance breeding efficiency.

Chilli (*Capsicum annuum*): In chilli, controlled light conditions significantly accelerate growth and reproduction. Under a PPFD of 420 $\mu\text{mol m}^{-2} \text{s}^{-1}$ and a 12-hour photoperiod, flowering occurs around 39 days after sowing, with viable seed production by 82 days. Extending the photoperiod to 20 hours advances flowering by 2–3 days. Supplementation with far-red light improves fruit ripening and seed germination, allowing up to four generations per year.

Pea (*Pisum sativum*): In pea, an integrated in vitro–in vivo system combined with hydroponics and a 22-hour photoperiod enables up to four generations annually. Growth under controlled temperatures ($20\pm 2^\circ\text{C}$) and the use of growth regulators promotes early seed development. This method is more efficient than conventional field-based single seed descent, particularly for handling segregating populations.

Advantages of Speed Breeding

1. Enables the production of multiple generations within a single year, significantly accelerating breeding programs.
2. Facilitates rapid development of completely homozygous lines through the single seed descent method.
3. Allows effective phenotypic selection even in early segregating generations, improving selection efficiency.
4. Supports quick introgression of desirable genes into elite lines when combined with marker-assisted selection techniques.
5. Provides opportunities to study important traits such as plant–pathogen interactions and flowering behaviour under controlled conditions.
6. Simplifies the execution of multi-environment trials across different years within a shorter time frame.
7. Can be efficiently integrated with advanced tools like genomic selection and genome editing technologies.
8. Enables high-throughput phenotyping for evaluating multiple traits simultaneously.
9. Enhances the utilization of gene bank accessions and mutant populations for rapid identification and characterization of useful genes.

Challenges in Speed Breeding

1. Shortage of skilled and trained plant breeders to effectively implement the technique.
2. Limited infrastructure facilities, along with inconsistent water and electricity supply, affecting reliable operation.
3. Absence of standardized protocols for different crops and growing conditions.
4. High initial investment required for setting up controlled environments and equipment.
5. Early harvesting of seeds may hinder accurate phenotyping of certain seed-related traits.
6. Variation in response among plant species to extended photoperiod conditions, limiting uniform application.
7. Increased risk of disease incidence due to controlled and intensive growing environments.
8. Difficulty in effectively incorporating complex, quantitatively inherited traits into breeding programs.

Conclusion

Speed breeding is a powerful approach that significantly accelerates the development of superior crop varieties by reducing the time, space and resources required for selection and genetic advancement. It enables plant breeders to rapidly improve existing high-performing cultivars with desirable traits. The integration of speed breeding with advanced techniques

such as marker-assisted selection and genetic engineering further enhances the efficiency of identifying elite genotypes with improved yield, quality and tolerance to biotic and abiotic stresses.

In resource-limited countries like India, speed breeding offers a highly practical solution to shorten breeding cycles and intensify research programs. By optimizing input use and increasing efficiency per unit area, this technique holds great potential for strengthening crop improvement efforts and ensuring sustainable agricultural productivity in the face of growing food demands

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