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13. Speed Breeding for Crop Improvement

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Abstract:

Speed breeding is a new plant breeding technique that has the potential to revolutionize crop improvement. By using controlled environments and genetic markers, speed breeding can reduce the time it takes to complete a breeding cycle from years to months. This makes it possible to develop new varieties that are more resistant to pests and diseases, possessing unique qualities having higher commercial values, more tolerant of changing climatic condition, and have higher yields in shorter period of time, resulting into higher genetic gain per unit time invested in crop breeding. The future prospects of speed breeding for crop improvement are very promising. With further research and development, speed breeding could be used to: Meet the needs of feeding a growing global population and world's most pressing food security challenges, improve crop yields, nutrition and other qualities specific for the crop, Increase the resilience of crops to pests, diseases, and climate change, develop new crops that are better suited to specific environments using biotechnology and wide crossing techniques and reduce the cost of crop improvement.

Here are some concrete instances of how crop yields and nutrition could be enhanced by speed breeding: It could be used to develop new varieties of wheat that are more resistant to drought and heat stress. This would be a major benefit for farmers in developing countries, who are often struggling to grow crops in dry conditions, Speed breeding could be used to develop new varieties of rice that are more tolerant of flooding.

This would be important for farmers in countries that are prone to flooding, such as Bangladesh, lowlands in India, and parts of other Asiatic countries Speed breeding could be used to develop new varieties of fruits and vegetables that are more nutritious. This would be beneficial for people who are looking to improve their diet. Moreover, it will be beneficial to combat malnutrition in childrens in poor societies of the world and Speed breeding is still a relatively new technique, but it is quickly gaining momentum. In the coming years, we can expect to see speed breeding being used to develop new crop varieties that will help to feed a growing global population and improve the quality of life for people around the world.

Keywords:

speed breeding, lights, horticulture, climate change, stress, control environment, generation advancement.

13.1 Introduction:

Global food security is becoming the major concern in devastating climate change scenario and the expanding human population, as the current improvement rate of several staple and economical crops doesn't seem to file to meet the needs of near future [1]. Speed breeding is the tool to fasten the breeding cycle by shortening the generation time as plants are grown in fully enclosed, controlled environment, growth chamber and help in precise phenotyping, mutant studies and transgenic screening this approach was first adopted at University of Queensland and University of Sydney. Rapid Generation Advancement facility has been established in UAS, Dhadwad. Recently, establishment of Speed Breeding infrastructure has been proposed in 4 universities in India.

With using this technology, having the ability to manipulate the photoperiodic condition and temperature requirements of the crops, up to 6 generations per year for photo insensitive crop plants and 2-3 generations for rest of the plants have been achieved. For example, in *Arabidopsis thaliana*, 10 generations per year can be grown by decreasing the time of flowering to 20-26 days, by manipulating the ratio of plant growth regulators and photoperiodic requirement of the plant along with facilitating immature seed germination [2]. Along with flowering, seed maturation and drying are also accelerated, as normal seed ripening takes around 15 days but in speed breeding program, harvesting of immature spikes and their artificial drying in dehydrator takes almost 3 days, facilitates faster a cycle. Originally it was developed for crop breeding and research but now it also being used for industrial purposes. In order to enhance the rate of crop improvement, we see enormous possibilities for merging speed breeding with other contemporary crop breeding tools and technologies, including as high-throughput genotyping and phenotyping, genome editing, MAS and genomic selection.

13.1.1 History:

About 100 years back Pfeiffer (1926) [3], a botanist, first reported that plants can be grown under an artificial source of light. The effects of continuous supplemented light by using incandescent and electric lamps were studied by Siemens (1880).

Subsequently, it was reported that continuous light induces early flowering in several plant species, including cereals, pulses, weed species, vegetables, herbs, and ornamentals (Davis and Burns, 2016) [4] Group of botanists at NASA, USA, working on developing methods to grow crops in space to overcome the challenge of long growing time of major food crops imposing: difficulty to produce enough food for astronauts.

In order to grow food at a faster pace in space, NASA researchers developed a method called "forced flowering", which involved using high-intensity light and prolonged photoperiods to accelerate plant growth and flowering.

This method was successful in reducing the growing time of wheat by up to 50%, and it paved the way for the development of speed breeding, Researchers at University of Queensland, Australia, the John Innes Centre, UK and collaborators optimized the techniques suitable for rapid plant growth and coined the name 'speed breeding' in 2003 [5].

They found that by using a combination of high-intensity light, extended photoperiods, and optimal temperature, moisture regime and nutrient conditions, they could significantly reduce the period of breeding cycle of a variety development from 10-12 years to 2-3 years. Dr. Lee Hickey at university of Queensland, Australia, was developed "DS Faraday", the first wheat variety through speed breeding having high protein content, good milling quality and tolerant to pre harvest sprouting [6].

Since then, speed breeding has been used to accelerate the development of new crop varieties for a variety of purposes, including improving resistance to pests and diseases, increasing yield, along with developing resistance to multiple abiotic stresses in changing climatic conditions, indicates its potential to meet the challenges of global food security.

Here are some of the key milestones in the history of speed breeding:

- 1926: Pfeiffer suggested that plants can be grown in artificial light condition.
- 1980s: NASA develops 'forced flowering' method to accelerate plant growth in space.
- 2003: Researchers at the University of Queensland coined the term "speed breeding".
- 2006: First commercial speed breeding facility opens in the Netherland.
- 2010: Speed breeding is used to develop a new variety of wheat that is resistant to the stem rust disease and having other novel characters.
- 2015: Speed breeding is used to develop a new variety of barley that is more tolerant to drought.
- 2020. Speed breeding is used to develop a new variety of rice that is more resistant to flooding [7].

13.2 Methods and Techniques:

Speed breeding is plant breeding technique that uses controlled environmental conditions to accelerate the generation time of crop plants. This can be done by manipulating a number of factors, including light intensity, photoperiod, temperature, and nutrient availability.

Here are some of the most common methods and techniques of speed breeding:

A. **High-intensity light:** This is one of the most important factors in speed breeding. High-intensity light helps to increase the rate of photosynthesis, which in turn leads to faster plant growth. High-intensity light can he provided by artificial lights or by using sunlight through greenhouses or growth chambers.
B. **Extended photoperiods:** This means providing plants with more than the minimum amount of daylight. Extended photoperiods can he achieved by using artificial lights or by adjusting the timing of sunrise and sunset in greenhouses or growth chambers.
C. **Optimal temperature and nutrient conditions:** In addition to high-intensity light and extended photoperiods, it is also important to provide plants with optimal temperature and nutrient conditions. This means providing plants with the right amount of heat and the right balance of nutrients.
D. **Using immature seed:** This method involves using seed that is not yet fully mature. Immature seed is more sensitive to light and temperature, which can help to accelerate plant development. They are forced to dry in dehydrator in shorter period of time.
E. **Using single seed descent:** This method involves planting single seed from each plant and then selecting the best plants to continue the breeding program. This method can help to maintain genetic diversity and to select for the most desirable traits.
F. **Using marker-assisted selection:** This method uses genetic markers to identify plants with the desired traits. Marker-assisted selection can help to speed up the breeding process by allowing breeders to focus on the plants that are most likely to be successful.
G. **Using genomic selection:** This method uses genomic data to identify plants with the desired traits. Genomic selection a more advanced method than marker-assisted selection, and it can be used to select for traits that are not easily identified by genetic markers.

Integration of speed breeding techniques with Artificial Intelligence can lead to a more precise and fruitful breeding results.

Breeder's equation:

To examine the suitability of the particular crop plant for breeding via speed breeding techniques:

$$Rt = ir\sigma a/y$$

Where,

Rt = genetic gain
over time i =
selection intensity r
= selection accuracy
σa= genetic variance
y = years per cycle

The genetic gain over time (Rt) increases with increase in selection intensity(i), selection accuracy(r) and genetic variance (σa) and with decrease in years per cycle (y) and vice versa. An increase in selection accuracy increases phenotyping and reduces error [8].

13.3 Core Recipe of Speed Breeding:

The main 'recipe' for setting up speed brooding conditions includes:

A. **Light:** The Photosynthetically Active Radiation (PAR), comprising Red, Far Red and Blue range of wavelength 400-700 mm are best to use in speed breeding chambers. LED bulbs and combination of LED and halogen bulbs are used to maintain this spectrum. It is also advised to maintain a photosynthetic photon flux density (PPFD) of 450-500 mol/m2/s at plant canopy height, however this value can he adjusted lightly lower or higher depending on the needs of the crop and its stage of development.

B. **Photoperiodic regime:** A photoperiod of 22-hour light and 2-hour darkness in diurnal cycle of 24 hours is ideal photoperiodic regime for speed breeding. Whereas relative duration of light and dark period can be optimized crop to crop, another alternative is continuous light but slight period of darkness is known to improve the health of plant.

C. **Temperature:** Optimum temperature for each crop should be maintained. A higher temperature should be maintained during the photoperiod, while a dip in temperature during the dark period can aid in stress relief. Elevating temperature can speed up generation time because it has a significant impact on how quickly plants develop. However, in some circumstances, a greater temperature might cause conditions similar to stress and damage a plant's performance Care should be taken to maintain the temperature difference between light and dark period.

D. **Humidity:** Regulating the humidity 60-70% RH is optimum for crop growth, even in climate- controlled chambers, and this level can he adjusted depending on the crop. Lower humidity levels are advised for crops that are better suited to arid environments.

13.4 Procedure of Speed Breeding:

A general procedure for low-cost speed breeding in a homemade growth room design is as follows:

Material Required:

- A room with insulated sandwich paneling
- Seven LED light boxes
- A 1.5 horsepower inverter split system domestic air conditioner
- Irrigation Controller
- Spike dripper
- 90 pots of 20.3 cm

Procedure:

- Set up the room with the LED light boxes and air conditioner.

- Place the pots in the room and fill them with soil.
- Sow the seeds in the pots.
- Set the light timer to 12 hours of light and 12 hours of darkness.
- Increase the light timer to 18 hours of light and 6 hours of darkness after 4 weeks.
- Set the temperature to 21°C during the photoperiod and 8°C in darkness.
- Water the plants regularly.
- Harvest the seeds when the plants are mature.

Notes:

- The light quantity should range from 210-260 µmol m^{-2} s^{-1} at bench height and 340590 µmol m^{-2} s^{-1} at 50 cm above the pot.
- The humidity conditions should be ambient.
- The lighting should be enriched in the blue, red and far-red part of the spectrum.
- Speed breeding approach is ideally realized using Single Seed Descent method.
- By increasing the sowing density in speed breeding, we can achieve rapid cycling of many lines having healthy plants and viable seed.
- The plants grown under speed breeding reached anthesis in approximately half time us compared to those grown in same conditions under glasshouse conditions.

This procedure has been used for speed breeding of wheat, barley, oat and triticale.

13.5 Advantages of Speed Breeding:

A. **Reduced breeding time:** Speed breeding can shorten breeding cycles by two to three times, compared to conventional breeding. This means that new crop varieties can be developed more rapidly, which is essential for meeting the challenges of climate change and food security.

B. **Increased selection efficiency:** Speed breeding allows for more efficient selection of desirable traits, because plants can be grown and evaluated under controlled conditions. This reduces the number of plants that need to be grown and evaluated, which saves time and resources.

C. **Improved phenotyping:** Speed breeding can be used to improve phenotyping, which is the process of measuring and evaluating plant traits. This is because plants can be grown under controlled conditions, which makes it easier to measure traits that are difficult to measure in the field.

D. **Increased genetic diversity:** Speed breeding can be used to increase genetic diversity in crop populations. This is because it allows for the rapid evaluation of large numbers of genotypes, which can help to identify new sources of desirable traits.

E. **Lower cost:** Speed breeding can be a more cost-effective way to breed crops than conventional breeding. This is because it requires less land, labor, and resources. Speed breeding is a promising plant breeding technology, but it does have some draw backs too.

13.6 Disadvantages:

A. **Cost:** Establishment of infrastructure for speed breeding needs very high initial cost. It requires specialized facilities and equipment, which can be expensive.
B. **Labor:** Speed breeding requires more labor than conventional breeding, because plants need to be grown and evaluated under controlled conditions. This can be reduced by adopting automated sensor-based practices.
C. **Infrastructure:** Speed breeding requires access to controlled environments, such as growth chambers or greenhouses. This may not be available in all regions or for all crops.
D. **Training:** Speed breeding requires specialized training, which may not be available in all regions.
E. **Phenotypic plasticity:** Speed breeding can lead to phenotypic plasticity, which means that the expression of a trait can vary depending on the environment. This can make it difficult to select for desirable traits.
F. **Genomic instability:** Speed breeding, can lead to genomic instability, which means that the DNA of the plant can be altered. This can have unpredictable effects on the plant, such as reduced yield or increased susceptibility to disease.

Overall, speed breeding is a promising technology with the potential to revolutionize crop improvement. However, it is important to be aware of the potential disadvantages before using this technology.

13.5 Additional Considerations for Using Speed Breeding:

A. **The type of crop:** Some crops are more amenable to speed breeding than others. For example, crops with short generation times, such as rice and wheat, are more suitable for speed breeding than crops with long generation times, such as trees.
B. **The target traits:** Some traits are more difficult to select for using speed breeding than others. For example, traits that are affected by the environment, such as yield, are more difficult to select for than traits that are not affected by the environment, such as resistance to a specific discase.
C. **The breeding program:** Speed breeding can be used in a variety of breeding programs, but it is most effective in programs that are focused on developing new varieties quickly.

Overall, speed breeding in a powerful tool that can be used to revolutionize crop breeding. However, it is important to carefully consider the potential advantages and limitations in advance.

13.6 Applications of Speed Breeding:

13.6.1 Crop Improvement:

- Speed breeding is not labor-intensive and affordable; thus, it might be extensively practiced even in regions of poverty.

- Many germplasms might be cultivated densely in a compact area, which would be particularly valuable for large-scale population screening.
- Speed breeding might be done at any time of year, independent of external conditions or climatic changes.

13.6.2 Studying Physiological Traits:

It may be expanded to investigate important physiological features in agricultural plants. For example, deployment of speed breeding has been done in durum wheat and selection has been done for key traits like seminal root angle, seminal root number, tolerance to crown rot, resistance to leaf rust, and plant height. These features are advantageous in durum wheat in areas where production is limited by in-season rainfall and the incidence of tolerance to crown rot and resistance to leaf rust outbreaks.

Table 13.1: Examples of Speed Breeding in Various Crop Plants

Crop	Goal	Generation per year	Approach utilized	Reference
Durum wheat	Resistance to crown rot	6	Speed breeding with multi-trait phenotyping	(Alahmad *et al.*, 2018)
Arabidopsis	Rapid generation advance	NA	Extending light exposure through supplemental light with SSD	(Watson *et al.*, 2018)
Soybean	Rapid generation advance	5	Extending light exposure through supplemental light and LED lighting under SB for short-day plant	(Jähne *et al.*, 2020)

13.6.3 Transgenic and Crispr research and Use of Genomics:

For the estimation of breeding value of quantitative characteristics (e.g., yield) in wheat, genome-wide selection has been integrated with speed breeding (Watson *et al.*, 2019). Before field experiments, recombinant inbred lines were developed using an integrated genomic selection and speed-breeding method, which permitted indirect phenotypic selection for the enhancement of critical characteristics like as height and flowering time (Watson *et al.*, 2019).

Predicting a plant's performance for any attribute, such as yield or quality, stress or disease, field-testing procedures, and predictive breeding cycles may be extremely quick. Researchers want to employ artificial intelligence in the future to anticipate plant performance based on genotyping, as well as the optimal parents to use for crossing.

13.7 Challenges of Speed Breeding:

Because of photoperiod sensitivity, the response of short-day plants to speed breeding is not as successful as that of long-day or day-neutral plants; however, recent progress has been made for soybean (*Glycine max*), rice (*Oryza sativa*), and amaranth (*Amaranthus* spp.) using LED lighting systems.

- Prolonged photoperiod can harm plant growth and development by causing wilting, chlorosis, and reduced biomass.
- A totally enclosed habitat can lead to significant insect and disease outbreaks.
- Unreliable water and power supply for long-term operations: A consistent and dependable supply of water, energy, and other resources required to run speed breeding facilities remains a difficulty in many underdeveloped nations.
- There is a scarcity of qualified plant breeders and breeding technicians.
- Inadequate infrastructure facilities.
- Streamlining operations and automating procedures must yet be improved.

13.8 Future Prospects:

By lowering the amount of time, space, and resources involved in the selection and genetic progression of better crop varieties, speed breeding can hasten the production of high performing cultivars with market-preferred features. Furthermore, combining speed breeding with traditional, MAS, and GE breeding methods can improve the effective selection of elite genotypes and lines with innovative features such as improved yield and nutritional quality, as well as biotic and abiotic stress tolerance.

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