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Speed Breeding- An Emerging Trend in Crop Improvement

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Authors' contributions

This work was carried out in collaboration between both authors. Author SLS collected the literature and written the manuscript. Author SS revised the manuscript and made final manuscript. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

During the past century, traditional breeding programs resulted in several significantly better types in a variety of unique breeding programs around the world. The plant develops slowly because of the lengthy breeding cycle, which can take ten to fifteen years from the cross to cultivar release. That stated it is quite difficult to combine multiple polygenic traits using traditional breeding methods. Speed breeding is a technique that reduces the length of the breeding cycle by lengthening the photoperiod and adjusting other glasshouse growth factors like temperature, soil type, spacing, etc. Rapid generational advancement is made possible by this strategy. Speed breeding yields 3 to 9 generations annually as opposed to 1 to 2 generations annually using standard selection processes. Instead of 2-3 generations per year under typical glasshouse conditions, speed breeding can produce up to 6 generations per year for spring wheat, durum wheat, barley, chickpea, and pea, and 4 generations for canola. Speed breeding, thus, permits the rapid generation of stable and homozygous genotypes.

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1. INTRODUCTION

"In crop breeding, the traditional method involves choosing parental genotypes that complement each other and have the desired features. subsequently, crossings, selections, and the development of superior progenies are required to produce candidate cultivars that satisfy market expectations" [1]. "Notable breeding objectives in crop cultivar improvement programs include higher production potential, enhanced nutritional quality, and increased tolerance to biotic and abiotic challenges" [2,3]. "In any crop development program, the following breeding procedure can be identified in the following order: The process involves selecting desirable parents whose traits complement each other, crossing the selected parents and watching how the progeny develop, selecting and genetically advancing the best progeny based on target traits, and selecting the best progeny for screening in multiple target traits" [1].

"Many agricultural cultivar development initiatives make use of these conventional breeding methods. However, it can take conventional breeding procedures more than ten years to create and release an improved variety in the absence of an integrated pre-breeding effort" [4,5]. Many variety design programs focus on time, space, and resources mostly on the breeding procedure's evaluation and parent selection. The amount of time spent in these phases considerably reduces the rate at which cultivars become economically feasible. In conventional breeding, the rate of advancement of each generation is modest, and selecting procedures in the field takes an entire growing season. A single breeding generation yields a range of crops, including cassava, in 15 to 18 months. There can only be one agricultural cycle per year due to variable meteorological circumstances like high temperatures, erratic rainfall patterns, and extended days. It is also possible to produce two generations annually in certain tropical crop-producing environments [6].

"By modifying the environmental conditions in which crop genotypes are produced, speed breeding refers to a broad range of techniques aimed at advancing crop genotypes to the next breeding generation as quickly as possible by speeding up seed development and flowering. Rapid generation progress reduces costs and the length of the breeding cycle. A few selection techniques that can be applied in speed breeding to shorten the breeding cycle and make effective use of resources are single seed descent (SSD), single pod descent (SPD), single plant selection (SPS), clonal selection, and marker-assisted selection (MAS)" [7-9].

About three to nine generations are generated annually with speed breeding, as opposed to one to two generations through traditional selection techniques [10]. Therefore, homozygous, and stable genotypes can be achieved quickly by speed breeding, leading to the introduction of novel cultivars. [9]. Furthermore, for multiple trait selection, high-throughput phenotyping approaches and MAS work well with speed breeding technologies.

This paper attempts to explain the primary advantages and drawbacks of speed breeding, as well as the selection techniques that can be used to progress the early generation. When compared to conventional breeding, which can take up to 8 to 10 years, the current analysis emphasizes the potential benefits of speed breeding for the successful development and release of agricultural cultivars in about 5 years.

2. PRINCIPLES OF SPEED BREEDING

The idea behind speed breeding is to use daylight length control of 22 hours of light, 22 ^{0}C during the day, and 17 ^{0}C at night with high light intensity and optimum temperature which varies depending on the crop, and optimal light quality. These factors generally speed up photosynthesis encouraging early flowering, seed maturity, and harvesting, and ultimately reduce the generation time needed for crop growth and development. To create an effective breeding line, single-seed descent is frequently combined with speed breeding [10].

2.1 Speed Breeding, I: Controlled Environmental Chamber Speed Breeding Condition (John Innes Centre, UK)

A regulated environmental chamber program is operated for a maximum of 22 hours of light and 2 hours of darkness, a temperature of 22°C of light and 17°C of darkness, and 70% humidity, with light sources including far-red LEDs, white LEDs, and ceramic metal hydrargyrum quartz iodide lamps with intensities of 360–380 (bench height) & 490–500 (Adult Plant height) μ mol m−2 s−1.

2.2 Speed Breeding II: Glasshouse Speed Breeding Conditions (Hickey Lab, Univ. of Queensland, Australia)

A temperature-controlled glasshouse with high-pressure sodium vapor lamps that have the following settings with photoperiod 22 hours of light and 2 hours of darkness, temperature 22°C of light and 17°C of dark with humidity of 70%, and light intensity 440-650 (Adult Plant height) μ mol m−2 s−1.

2.3 Speed Breeding III: Homemade Growth Room Design for Low-cost Speed Breeding (Hickey Lab, of Queensland, Australia)

An economically handcrafted structure measuring roughly 3 m x 3 m x 3 m, with insulated sandwich paneling, lighting equipment consisting of about 7-8 LED lightboxes, and a photoperiod of 12 hours by 12 hours (light-dark) for 4 weeks before increasing to 18 hours by 6 hours with a temperature of 21°C during the photoperiod and 18°C during the dark using light intensity 210–260 (bench height) & 340–590 (Adult Plant height)μ mol m−2 s−1

3. OPPORTUNITIES OF SPEED BREEDING TECHNIQUES

3.1 The Development of Homozygous Lines

Speed breeding techniques, which involve basic crossings of chosen parents with complementary traits, have been applied in several crops to quickly produce homozygous lines. The strategy depends on optimizing planting density, soil moisture, light intensity, temperature, and soil nutrition. By using these strategies to promote early blooming and seed set, the amount of time required to generate each breeding generation has been reduced. This process can yield three to nine breeding generations annually. This is ideal for rapid breeding under planned production circumstances and population assessment using multiple selection approaches such as SSD, SPD, and SPS [11].

3.2 Amenability with Selection Methods

The generation advancement through speed breeding is accepted, and it requires no phenotypic selection. On the other hand, target trait selection may effectively incorporate current technologies. In situations where plant growth is limited, the combination of speed breeding and efficient selection techniques should enable the maintenance of a healthy breeding population and genetic variety as well as the production of maximum yields [12]. To choose the genotypes that produce superior results, conventional selection techniques like bulk, mass, recurrent, pedigree, and pure line selection require a genetically stable plant population. As these approaches necessitate extensive phases of inbreeding and selection, they are not recommended for rapid breeding. Single plant selection (SPS), single pod descent (SPD), and single seed descent (SSD) are the most suitable selection techniques compatible with speed breeding. These techniques are explained in brief below.

3.3 Single Seed Descent Method

In single seed descent (SSD), one seed from each F2 plant is retained and these individuals are passed down to the following generation to continuously inbreed segregating populations until homozygous populations are achieved. Every inbred line that is created can be traced back to an F2 plant. Using SSD to create inbred lines takes less time than using the doubled haploid (DH) approach.

3.4 Single Pod Descent Method

Rather than selecting a single seed, the single pod descent (SPD) approach selects one pod per plant from each F2 through F4 plant. By following this method containing more than one seed per pod in most legume crops, SPD has a higher likelihood of preserving each F2 plant in the advanced generations than SSD selection.

3.5 Single Plant Selection Method

By gathering all the seeds from each chosen plant, the single plant selection (SPS) approach progresses every F2 plant. As a result, the following generation will progress from plant to row. To create introgression lines (ILs), a modified backcross strategy has been developed using the SPS method.

Table 1. Recent advancements in speed breeding

Type of Photoperiod	Family	Species	Generations/ Year	Reference
Long day	Poaceae	Oat (*Avena sativa*)	~7 generations	[20]
Long day	Poaceae	Barley (*Hordeum vulgare*)	~6 generations	[7]
Long day	Fabaceae	Clover (*Trifolium subterraneum*)	2.7–6.1 Generations	[21]
Long day	Fabaceae	Lentil (*Lens culinaris*)	~8 generations	[22]
Long day	Fabaceae	Chickpea (*Cicer arietinum*)	~6 generations	[9]
Long day	Fabaceae	Pea (*Pisum sativum*)	6.8 generations	[23]
Long day	Fabaceae	Faba bean (*Vicia faba*)	7 generations	[22]
Long day	Fabaceae	Narrow-leaf lupin (*Lupinus angustifolius*)	5 generations	[24]
Long day	Brassicaceae	Rapeseed (*Brassica napus*)	~5 generations	[9]
Long day	Linaceae	Flax (*Linum usitatissimum*)	~3 generations	[25]
Short day	Poaceae	Rice (*Oryza sativa*)	~4–5 generations	[26]
Short day	Poaceae	Sorghum (*Sorghum bicolor*)	4 generations	[27]
Short day	Fabaceae	Soybean (*Glycine max*)	~5 generations	[19,28]
Short day	Fabaceae	Pigeon pea (*Cajanus cajan*)	~4 generations	[29]
Short day	Fabaceae	Bambara groundnut (*Vigna subterranean*)	~4 generations	[30,31]
Short day	Fabaceae	Groundnut (*Arachis hypogea*)	~4 generations	[16]
Short day	Amaranthaceae	Grain Amaranthus (*Amaranthus* spp.)	~6 generations	[32,33]

4. COMMON CHALLENGES IN SPEED BREEDING

4.1 Lack of Trained Personnel

A shortage of qualified and employed plant breeding technicians in developing countries is an important challenge to speed breeding in the public sector. (Morris et al*.,*2006; Shimelis et al*.,* [1]). A few countries lack the proper legislative and administrative frameworks to govern the rights of plant breeders and regulate seeds, which would promote plant breeding and enhance the value chain that links farmers to consumers [13]. Therefore, to secure the sustainability of long-term crop improvement programs and the uptake of scientific advances like speed breeding, developing nations must modify their policies and practices regarding investments in plant breeding education, research, and personnel retention.

4.2 Inadequate Infrastructure

Institutional support is insufficient in public plant breeding programs in several developing nations. Speed breeding platforms require specialized infrastructure to regulate soil moisture, temperature, and photoperiod [14]. Also, there is a lack of the specialized tools required to carry out the trait selection process during early generation progress. As a result, while building infrastructure, national and regional organizations must actively collaborate and share resources and information. This relationship of cooperation continues after the infrastructure is established [15].

4.3 Cost of Establishment

The expense of speed breeding can be high, and the number of crossings and population sizes that can be assessed is sometimes limited by the size and management of an appropriate facility. This challenge should be addressed by speed breeding in conjunction with other modern breeding techniques, such as genomics-assisted breeding to capitalize on established marker-trait correlations, by focusing resources on plants that are most likely to contribute to the breeding objectives. By combining improved field trials with speed breeding, researchers can concentrate only on those aspects of the breeding program that stand to gain from acceleration, such as the parental crossing process in clonally propagated crops or those with long juvenile periods, or the creation of elite inbred lines following hybridization. Over half the price of speed breeding systems focuses on temperature regulation and lighting [16]. Using energy-efficient lighting like LED and air conditioning like inverter-based equipment can help cut this expense. Solar power can also be used to supplement the national grid's supply of gas and electricity [10].

5. APPLICATIONS OF SPEED BREEDING

Developing biparental and more complicated mapping populations, pyramiding traits, accelerating backcrosses, phenotyping adult plant traits, mutant study, and gene transfer studies are numerous instances of speed breeding applications [17]. Speed breeding helps in resolving challenges with doubled haploid technology such as inadequate vigor, poor germination rate, and even abnormal growth. Due to the various meiotic events that occur during repeated fertilization and the increased recombination frequency that results, recombinant inbred lines (RILs) created after several generations of self-fertilization can be preferable to DH for genetic mapping purposes. Similarly, given Speed breeding conditions, SSD can be used to develop and evaluate segregating generations quickly [18], which is more time and cost-effective than the traditional pedigree breeding approach [19].

6. CONCLUSION

By reducing time, space, and resources, speed breeding can hasten the production of high-performing cultivars with desirable market features by focusing on the genetic advancement and selection of superior crop varieties. With this method, crop variety improvements can be produced by breeders more quickly. The successful incorporation of speed breeding into a crop development program requires streamlined operations that minimize manpower and time constraints. Additionally, the successful selection of elite genotypes and lines with new characteristics can be improved by combining genetic engineering breeding techniques with marker-assisted selection and speed breeding. The SSD, SPD, and SPS procedures are the most suitable selection techniques compatible with speed breeding. However, many poor nations' adoption of speed breeding is constrained by the absence of qualified technicians and plant breeders, as well as the necessary infrastructure and dependable electrical and water supply.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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