SPEED BREEDING AND ITS IMPORTANCE FOR THE IMPROVEMENT OF AGRICULTURAL CROPS

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Abstract

Current environmental changes and continued global population growth represent a significant concern for food security. The slow rate at which current plant breeding programs are progressing is partly attributed to the long generation time of plants during the breeding process. One solution to overcome this obstacle is the use of Speed breeding technology that shortens the generation time to accommodate multiple generations of crops per year and accelerates crop research. The term "Speed breeding" was coined by Australian researchers in 2003 and is inspired by NASA experiments performed on a space mission. In this context, this paper summarizes some of the technological aspects, opportunities and limitations associated with Speed breeding. The integration of Speed breeding with other modern breeding technologies can further reduce the breeding cycle time and make selection for some novel traits more effective. Speed breeding is an innovative and promising breeding technology to ensure food security, which accelerates the development and release of new crop varieties.

***Key words**: growth chambers, photoperiod, single seed descent, speed breeding*

INTRODUCTION

Many improved cultivars have been obtained through conventional breeding methods. However, the increase in food demand as a result of global population growth exceeds current production levels. Also, the current climate change manifested by the increase of temperature and the reduction of precipitation caused emphasizing the effect of desertification in many countries. These climate changes have a negative influence on the metabolic processes of crop plants, which ultimately affect yield and quality (Bonea and Urechean, 2011; Ploae et al., 2012; Dima, 2014, Urechean and Bonea, 2017; Bonea, 2020). Therefore, new cultivars with high yields and resistant to biotic and abiotic stresses are needed. To achieve these goals, breeders have approached a novel strategy in plant breeding, called"Speed breeding". Speed breeding is a new breeding technology used by scientists to speed up the breeding process by increasing the number of generations per year (Watson et al., 2018). Thus, if through conventional methods, the development and release of new cultivars takes more than 10 years, through speed breeding it takes ~5 years (Wanga et al., 2021). Rapid development of genetically stable lines (homozygous lines) by Speed breeding depends on the manipulation of photoperiod, regulation of temperature and soil moisture, high-density planting, modifying carbon dioxide level and plant nutrition (hormones and organ tissue culture). Conventional selection methods (e.g. bulk selection, mass selection, recurrent, pedigree) are not ideal for Speed breeding, because they require long cycles of inbreeding and selection (Bonea, 2007; 2011). The more effective selection methods for Speed breeding are Single Seed Descent (SSD), Single Pod Descent (SPD), Single Plant Selection (SPS) (Wanga et al., 2021). Therefore, Speed breeding is a suite of techniques involving the manipulation of environmental conditions with the aim of accelerating flowering and seed set (Gosh et al., 2018). This method was first used in 1980 by National Aeronautics and Space Administration (NASA) in collaboration with Utah State University to grow wheat in space station, within an enclosed chamber of control environment and an extended photoperiod. Later, in 2003, inspired by the work of NASA, the Australian researchers of the University of Queensland proposed the term “Speed breeding” and used this technology at wheat cultivated in greenhouses to decrease the generational time period (Watson et al., 2018; Singh et al., 2021a; 2021b). The first spring wheat variety obtained through Speed breeding technology, called "DS Faraday", was released in 2017 in Australia. It has high protein content, tolerant to pre harvest sprouting and has milling quality (Shivakumar et al., 2021).

However, because Seed breeding mainly depends on extending the photoperiod through a continuous application of light, its potential is not realized for many plant crops (Pandey et al., 2022).

Recent research has demonstrated that combining the Speed breeding technology with other modern technologies such as genomic selection, genome editing, MAS (Marker-assisted selection), high-throughput phenotyping and genotyping, allows the acceleration of crop improvement (Singh et al., 2021a; Samantara et al., 2022; Sharma et al., 2022).

This review highlights some of the technological aspects, opportunities and limitations associated with Speed breeding.

SPEED BREEDING IN SINGLE-SEED DESCENT

In plant breeding programs for the development of cultivars which involves plantings in high density (such as cereal crops), the SSD (Single-Seed Descent) method is an imperative. The basic principle of this method used of Gosh et al. (2018) for wheat, barley, canola, pea, grasspea, *Brachypodium distachyon*, quinoa and oat cultivated in glasshouse and growth chambers is based on the following factors:

- light and light quality: use of optimal light covering PAR (photosynthetically active radiation), respectively 400–700 nm and with a photosynthetic photon flux density (PPFD) of ~450–500 μmol/m^2/s. These can be achieved using LEDs and halogen lamps;
- optimal growth temperatures for each individual crop (a temperature cycling regime of 22°C/17°C for 12 h of light and 2 h of dark or of 22°C/17°C for 22 h of light and 2 h of dark;
- an optimal photoperiod regime (22 hours of light and 2 hours of darkness in the daily cycle):
- an optimum humidity of 60–70% or lower for crops adapted to arid conditions RH is ideal for crop growth, this level can be changed depending on the type of crop. For crops more adapted to arid conditions, a lower level of humidity is recommended.

PROTOCOLS OF SPEED BREEDING

Watson et al. (2018) presented three Speed breeding protocols according to the resource availability:

- *Speed breeding 1* - controlled environmental growth chamber (Fig. 1) for wheat, barley and *Brachypodium distachyon* (with a photoperiod of 22 h provided by white LED bars, far red LED lamps, and metal HQI lamps, 22°C day/17°C night temperature and a humidity of 70%);

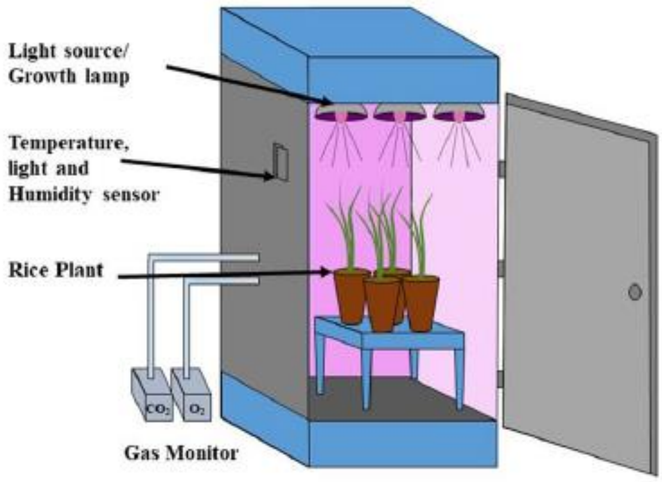

Figure 1. Growth chamber of Speed breeding (Source: Sharma et al., 2022)

- *Speed breeding 2* – glasshouse conditions (Fig. 2) for wheat, barley, canola and chickpea (with a 22 h photoperiod provided by high-pressure sodium vapour lamps and the same temperature conditions as SB 1);
- *Speed breeding 3* - low-cost homemade growth room design (Fig. 3) for wheat, barley, oat and triticale (included a insulated room of 3 m^3 with seven LB-8 LED light boxes and a 1.5 HP inverter split system domestic air conditioner. The lighting was adjusted to a 12 h photoperiod (12 h dark) for four weeks followed by 18 h light (6 h dark) and the temperatures were maintained at 18°C dark and 21°C light.

Recently, other several Speed breeding protocols have been developed in different plant crops (Nagatoshi and Fujita, 2019; Rana et al., 2019; Cazzola et al., 2020; Jahne et al., 2020).

IMPORTANCE OF SPEED BREEDING

Speed breeding is a suite of techniques that involves extending photoperiod and controlled environmental conditions aiming to accelerate flowering and seed set. This technology is revolutionizing agriculture by accelerating crop breeding activities such as crossing, back crossing, mapping population, rapid gene identification, pyramiding of traits, and developing transgenic pipelines (Hickey et al., 2019; Sing et al., 2022).

In conventional breeding, for any crop only one or two generations per year can be achieved, but in Speed breeding up to six (wheat, barley, pea and chickpea) or four generations per year (canola), allowing the rapid production of homozygous and stable genotypes (Watson et al., 2018).

The Figure 4 shows a comparison between the timelines of varietal development through (a) conventional reproduction and (b) Speed breeding (Samantara et al., 2022). Therefore, through conventional breeding, after crossing the parental forms, 5-10 years of inbreeding are needed to make a genetically stable (homozygous) line, and after stabilization 3-5 years are needed for field testing and 1-3 years for subsequent release of the cultivar, while through Speed breeding (due to the increase in the number of generations per year), after crossing only 1-2 years of inbreeding are needed to stabilize the lines and 3-5 years for field testing.

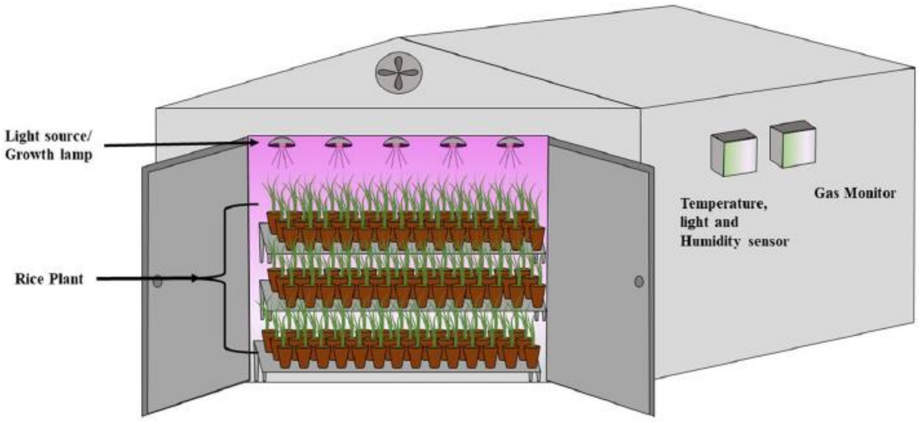

Figure 2. Glasshouse Speed breeding (Source: Sharma et al., 2022)

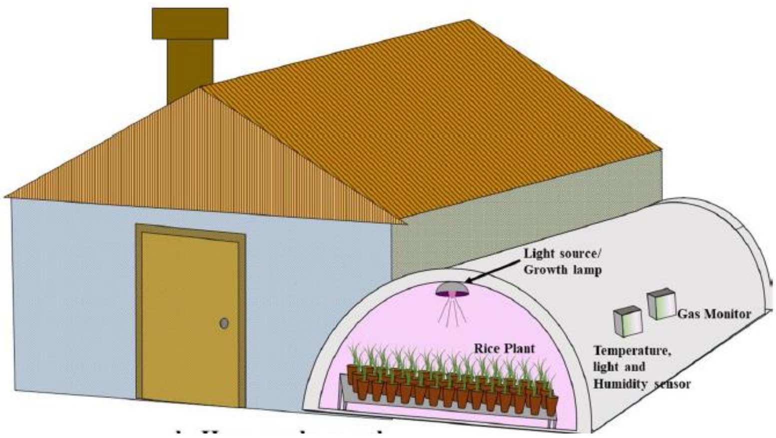

Figure 3. Homemade Speed breeding (Source: Sharma et al., 2022)

According to Watson et al. (2018), the availability of a low-cost growth room design highlights the versatility of the Speed breeding ‘recipe’, which can be tailored according to the local resources and purposes. To reduce the breeding cycle, plant breeders use other technologies such as Shuttle breeding and Double haploid technique. Speed breeding surpasses these technologies by producing a three times greater number of generations (Haroon et al., 2022).

Combining Speed breeding with other modern breeding technologies such as marker-assisted selection (MAS), genome selection, genome editing and high-throughput plant phenotyping (Figure 5), could improve some traits such as seed yield, seed quality, resistance to several diseases, tolerance to salt, plant height, accelerating genetic gain (Table 1).

Because the Speed breeding approach is carried out under controlled environmental conditions, it is possible to improve yield and quality of yield without the use of fertilizers and pesticides, an important aspect for organic farmers (Sharma et al., 2022).

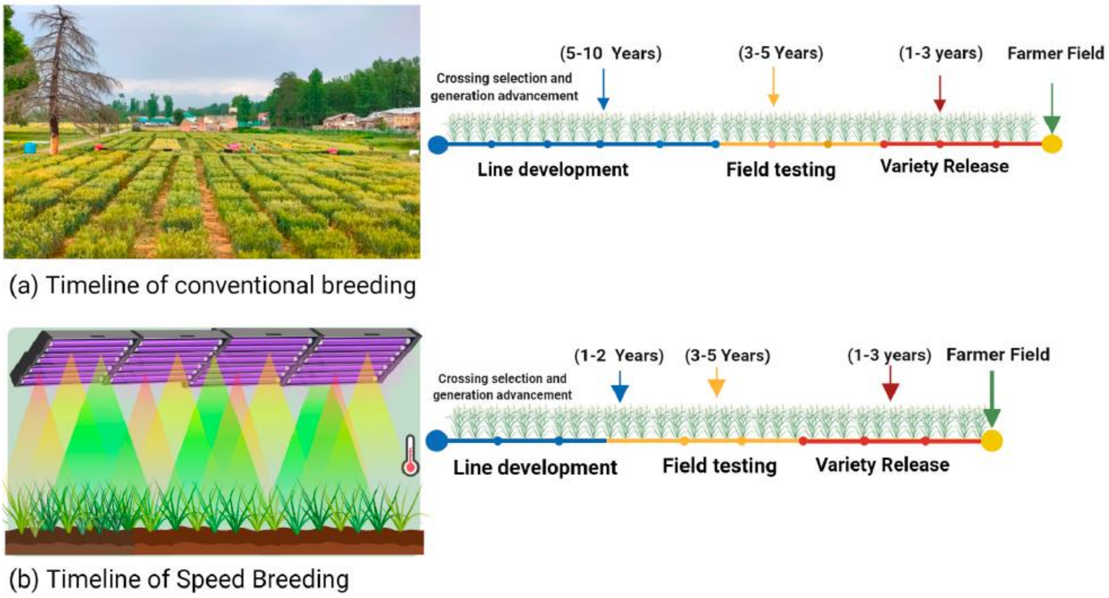

Figure 4. Comparison of timelines of varietal development by (a) conventional breeding and (b) Speed breeding (Source: Samantara et al., 2022)

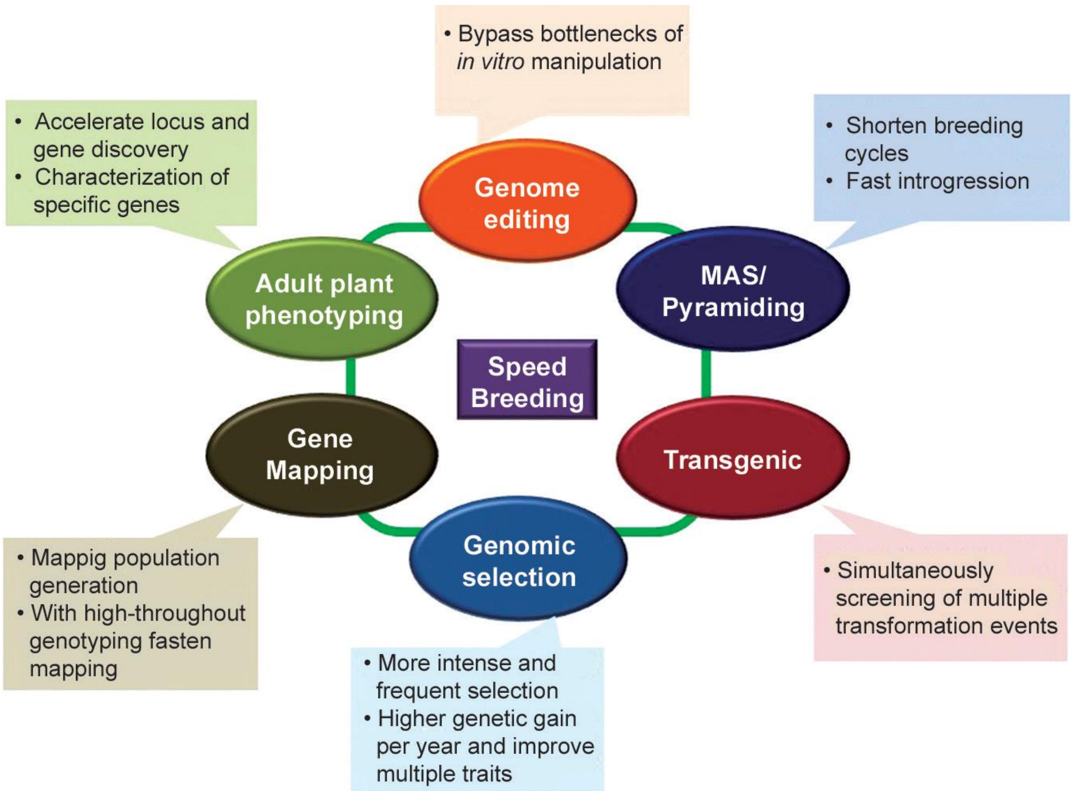

Figure 5. Speed breeding coupled with other breeding methodologies (Sources: Singh et al., 2021a)

Table 1. Examples of applications of Speed breeding technique for rapid generation advancement in different agricultural crops

Species	Trait/diseasses improved	Technique	No. of generations per year	References
Barley	Grain yield; Net and spot forms of net blotch and spot blotch, leaf rust	Speed breeding combined with high-throughput phenotypic screens for multiple target traits	4-6 generations per year	Hickey et al. (2017)
Wheat	Crown rot tolerance, resistance to leaf rust, seminal root angle and seminal root number	Speed breeding combined with multi-trait phenotyping	5 generations per year	Alahmad et al. (2018)
Rice	Salt tolerance	Speed breeding based genotyping and single nucleotide polymorphism (SNP) marker	4-5 generations per year	Rana et al. (2019)
Sunflower	Agronomic performane (plant height, head diameter, number of leaves, stem diameter, number of branches and seed number per head)	Speed breeding based by in vitro immature embryo culture.	4 generations per year	Dagustu et al. (2012)
Groundnut	Seed yield, seed quality, foliar disease resistance	Speed breding based genotyping and MEGS (marker-based early generation selection)	3.5 generations per year	Parmar et al. (2021)

LIMITATIONS OF SPEED BREEDING

Some major limitations of Speed breeding technology are:

- initial investment for growth chamber, lighting and temperature control requirement is high (Pandey et al., 2022);
- Speed breeding standardization is very difficult because of the differences between the photoperiodic state for a short day and a long day that vary from minutes to hours (Pandey et al., 2022);
- early harvesting of immature seeds may interfere with phenotyping of some traits of the seeds (Wanga et al., 2021);
- lack of properly qualified workers and opportunities for training and continuous professional development (Sharma et al., 2022).

According to Wanga et al. (2021), use of Speed breeding remains a challenge in resource-poor countries due to limited infrastructures, poor expertise, and limited collaborations with international organizations.

CONCLUSIONS

Speed breeding is a flexible procedure that uses prolonged photoperiods to increase the number of generations per year, thereby reducing breeding cycles including the time to obtain new improved cultivars for establishing nutritional security and sustainable agriculture.

The use of Speed breeding coupled with other modern breeding technologies will accelerate crop research and the improvement of cultivars with the desired traits in a short generation time.

To facilitate the application of Speed breeding worldwide, some measures should be considered, such as training of plant breeders and technicians, financial support and government support policies.

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