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Cultivating Tomorrow: The role of Speed Breeding in Future Crop Research

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Introduction

Agriculture, with its roots in ancient hunter-gatherer societies, has long been the source of food for humanity. Despite the ability to produce enough food for the world's current population of 8 billion, hunger is once again on the rise, affecting a staggering 10% of the global population. The World Food Programme attributes this resurgence to the ripple effects of the COVID-19 pandemic and the Ukraine conflict, which have triggered one of the worst food crises in recent decades. With the global population projected to surpass 8 billion and reach 10 billion by 2050, (Strzyżyńska 2022) farmers, governments, and scientists face the daunting task of boosting food production without worsening environmental degradation and climate change, which itself contributes to food insecurity in the global south. Traditional plant breeding, the cornerstone of agricultural progress for centuries, is too slow to meet these demands because of its over reliance on natural selection and hybridisation which are often time consuming. However, a promising solution has emerged in the form of a new technique known as speed breeding. During 1990s NASA in association with Utah State University investigated the possibilities of growing rapid cycling wheat in space station leading to development of new dwarf variety 'USU-Apogee'. Inspired from the previous effort scientists at the University of Queensland, the University of Sydney and the John Innes Centre, Australia polished and improved the technique and coined the term 'SPEED BREEDING'. Since then, speed breeding has been adopted by several research institutions and private companies across the world for various crops, including wheat, rice, chickpea, and pearl millet.

Methods

In this approach of speed breeding, the targeted crop is subjected to controlled environment like optimal day length, light intensity, light quality, temperature and moisture which helps to shorten the crop breeding cycle i.e. due to the induced alterations in the physiological processes such as photosynthesis rate, flower initiation and shorter reproductive cycles. Speed breeding even helps in multiple trait improvement in a short span of time by integrating high-throughput phenotyping techniques. By implementing selection methods such as single-seed descent method, single plant selection method, and marker-assisted selection, crop breeding cycle can be reduced to a remarkable level (as cited in the list below). Speed breeding as an umbrella term covers various techniques like accelerated single seed descent (aSSD: rapid development of homozygous lines), rapid generation cycling (RGC: more breeding cycles per year using DNA marker technology), fast generation cycling (FGC: more generations per year using stressed conditions and in vitro culture of immature embryos), rapid generation turnover (RGT: increasing numbers of generations per year using immature seed harvest and photoperiodic response) (Shanmugavel *et. al*, 2023)**.** There are 3 different speed breeding systems mostly used in crop improvement programs. These are

1. Controlled-environment chamber speed breeding. (Speed breeding-1)
2. Glasshouse speed breeding conditions. (Speed breeding-2)
3. Low-cost growth chamber speed breeding. (Speed breeding-3).

Here is a comparison among the 3 systems used in breeding programs: (Raju *et. al*, 2020)

Parameters	**Speed breeding 1**	**Speed breeding 2**	**Speed breeding 3**
Light source	Mixture of white LED bars, far-red LED lamps and ceramic metal hydrargyrum quartz iodine lamps	High pressure sodium vapour lamps	LB-8 LED light boxes
Light intensity	360-380 µmol/m2/s	440-650 µmol/m2/s	120-320 µmol/m2/s
Temperature	17º C during dark hours and 22ºC during light hours	17-22ºC	18º C during dark hours and 21ºC during light hours
Photoperiod	22 Hours	22 Hours	12-18 hours
Setup	BDW chamber	Glasshouse	A room of 3m×3m×3m

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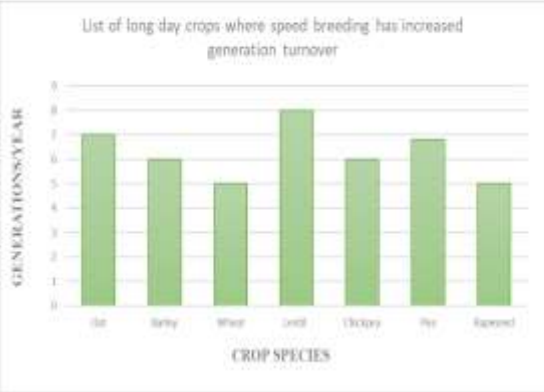

Table1: List of long day crops where speed breeding has increased generation turnover

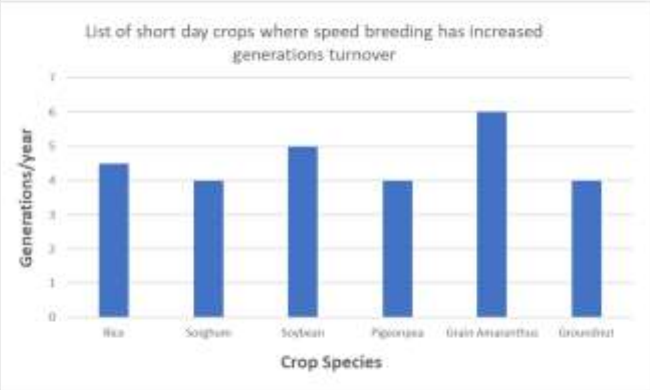

Table 2: List of short-day crops where speed breeding has increased generation turnover

Advantages of Speed Breeding: Speed breeding, an innovative plant breeding technique, offers immense opportunities for India's agricultural sector specially in development of new crop varieties to address the country's growing food security concerns, changing climatic scenario and enhancing the resilience of its agricultural systems. It can be summarised as follows:

1. **Shortening of breeding cycle:** Conventional plant breeding methods require many years to develop new crop varieties. On the other hand, Speed breeding, shortens this cycle through optimization of environmental conditions and manipulation of plant growth cycles. This accelerated breeding process allows the breeders to solve the emerging challenges more quickly (Table 1 and 2)
(Samantara *et al*., 2022)
2. **Enhancing Nutritional Quality:** Speed breeding can be efficiently employed to improve the nutritional content of staple crops, to solve the widespread malnutrition and micronutrient deficiencies in India. By improving specific genes responsible for nutrient biosynthesis, breeders can develop crops with increased levels of essential vitamins, minerals, and antioxidants.
3. **Multiple trait improvement:** Climate change is considered to be a significant threat to India's agricultural sector, with extreme weather events and erratic rainfall patterns impacting crop yields. Speed breeding can fast forward the development of climate-resilient crops by incorporating multiple genes from wild relatives or using gene editing

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techniques that can tolerate drought, salinity, and other environmental stresses. For example salt tolerant line Yukinko-mai has been developed in rice through combined MAS and speed breeding technique (Rana *et al.*, 2019).

4. **Promoting Sustainable Agriculture:** Speed breeding can contribute to sustainable agricultural practices by reducing the need for extensive field trials and resource-intensive breeding programs. By enabling the rapid evaluation of genetic traits in controlled environments, speed breeding can minimize the use of pesticides and fertilizers, promoting eco-friendly and sustainable agricultural practices.
5. **Empowering Smallholder Farmers:** Speed breeding can empower smallholder farmers by providing them improved crop varieties specific to their needs and agroecological conditions. By developing varieties that are high-yielding, biotic and abiotic stress resistant, speed breeding can enhance the productivity and profitability of smallholder farms.
6. **Fostering Innovation and Collaboration:** Speed breeding technology has the potential to promote innovation and collaboration within India's agricultural research and development sector. By establishing speed breeding facilities and training programs, India can nurture a force of skilled personnel equipped with the knowledge and expertise to utilize this technology effectively.

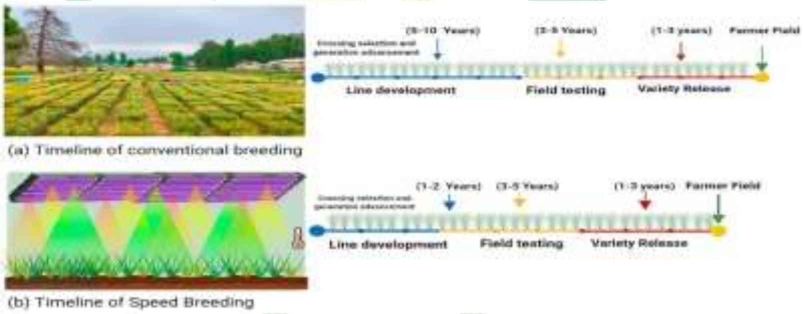

Figure 1. Timelines of varietal development with a) conventional breeding b) speed breeding Source: Breeding more crops in less time: a perspective on speed breeding by Kajal Samantara et. al, published in Feb 2022.

Challenges in implementing speed breeding technique

- **Lack of skilled personnel:** Many developing countries lack the necessary expertise to implement speed breeding effectively. This is due to several factors, including a high turnover of plant breeding personnel to the private sector, a limited number of universities offering postgraduate qualifications in plant breeding, and an underdeveloped legislative and administrative framework for managing plant breeders' rights and seed regulation. To address this challenge, developing countries need to invest in plant breeding education and research, and develop policies that encourage the retention of plant breeding personnel. (Wanga *et. al*, 2021.)

- **Inadequate infrastructure:** Speed breeding platforms require sophisticated equipment and setup to regulate environmental factors. However, many developing countries lack the type of infrastructure needed for the speed breeding program. To overcome these challenges, developing countries need collaborative efforts to maintain the adequate infrastructure facilities and resources. Innovative solutions, such as the use of modified shipping containers fitted with solar-powered temperature and light control equipment, could also help to reduce the cost of establishing new infrastructure.
- **Lack of government support and inter program collaboration:** As of now government interventions in speed breeding is not satisfactory. Most of the speed breeding programs are lacking continuous financial assistance and unsupported policies add up to the concern. Moreover erratic water and electricity supply is also another constrain for speed breeding programme as indoor facilities require a consistent supply of electricity and water for cooling, heating, and lighting etc.

Conclusion:

The emergence of speed breeding technology in plant breeding offers a powerful approach to accelerate crop improvement and also pave a new dimension of future crop research. While it takes almost more than 10 years from crossing to selection of a crop through conventional breeding program, speed breeding can take us there in less than 3 years' time. Such drastic reduction in the generation cycle is achieved by manipulating environmental conditions enabling breeders to generate multiple generations per year and rapidly progress through breeding cycles that is the need of the hour. This accelerated breeding technique holds immense promise for developing new cultivars with enhanced traits such as yield, disease resistance, and adaptability to environmental stresses that gives the solution for climate changes and sustainability. Also, the integrative nature of the technique with single-seed descent (SSD) and Marker-assisted selection (MAS) opens up new opportunities for the breeders. In conclusion, speed breeding, empowered by advances in genomics and phenomics, offers a

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transformative approach to crop improvement to address global food security challenges and deliver improved cultivars to meet the demands of a growing population.

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