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Speed Breeding: A Silver Lining for Global Food Security

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Speed breeding is an innovative breeding technology that improves crop varieties by reducing their generation time and by creating an artificial environment. This type of technology is the advancement of the conventional breeding method. Speed breeding is such a powerful tool for rapid generation advancement that significantly reduces the harvest time of crops to speed up agricultural research. It increases the production of food to meet the demand of the growing

The concept of Speed breeding came into existence 150 years ago, where botanists first showed that under artificial light the plants can grow. In the mid-1980s, NASA collaborated with 'Utah State Unisversity to explore the rapid growth cycle of plants under constant light on the International space station(ISS) on wheat. After that Dr. Lee Hickey adopted NASA's Plan for the production of wheat and peanut at the University of Queensland, John Innes Centre, and the University of Sydney in Australia. So, Queensland University coined the term Speed Breeding in 2003 (Bugbee, *et al.*, 1997). 'DS Faraday' was the first spring wheat variety that was developed by using speed breeding and released in 2017 in Australia.

Principles of Speed Breeding

The principle behind speed breeding is to use optimum light intensity, light quality, optimum temperature (varied according to crop), and daylight length control (22 h light, 22oC at day/17 ^{0}C at night with high light intensity) (Ghosh *et al.*, 2018) which generally accelerates the rate of photosynthesis and stimulates early flowering, seed maturity, harvesting and ultimately shortens the generation time required for crop growth and development. Commonly speed breeding is coupled with single seed descent for developing an efficient breeding line and elite inbred line.

Basic requirements - Standard protocol and greenhouse design for speed breeding

The successful approach of the speed breeding program requires a proper channel and set-up requirements. Controlled greenhouse structure, light requirements, humidity, temperature, and germplasm -these are necessary for speed breeding programs

a) Speed breeding I: Controlled environmental chamber speed breeding condition (John Innes Centre, UK)

A controlled environmental chamber program is run for up to 22-hour of photoperiod, with an optimum temperature of 22^{0}C during the photoperiod, and about 17^{0}C during the 2-hour dark period. An artificial photoperiod can be applied by a mixture of white LED, far-red LED & Ceramic metal hydrargyrum quartz iodide lamp.

b) Speed breeding II: Glasshouse speed breeding conditions (Hickey Lab, Univ. of Queensland, Australia)

A temperature-controlled greenhouse is fitted and maintained at 17/22℃ optimum temperature , with sodium vapour lamps and 12 hours of turnover and 22-hour of photoperiod (Ghosh *et al.*, 2018). Light intensity is maintained as 440-650 µmol $^{m-2}$ s $^{-1}$ at adult plant.

c) Speed breeding III: Homemade growth room design for low-cost speed breeding(Hickey Lab, of Queensland, Australia)

A low-cost homemade structure consists of about 3 m x 3 m x 3 m dimensions with insulated sandwich paneling and fitted lighting equipment of about 7-8 LED lightboxes. Light quantity should be 210-260 µmol m-2 s -1 and at 50 cm above the pot from 340-590 µmol m^{-2} s^{-1} (Adult plant height).

Speed breeding as a tool in other breeding methods

Nowadays, Speed breeding can be combined with several different technologies to accelerate the growth of crops with controlled temperature and light. Some of the important combination techniques have been discussed below.

a) Enhancing Genetic Gain by speed breeding and Genomic selection: Genetic gain can be improved by speed breeding along with genomic selection. It can reduce the length of the breeding cycle and produces a superior quality of plant variety at a very short duration which improves the genetic gain.

b) Multiple disease resistance by Speed Breeding: To reduce the effect of evolving pathogens, plant breeders are discovering different ways to enhance the quality of crop production. Hickey *et al.* 2017, carried out research in which they applied the two-rowed barley cultivar, Scarlett, with novel methods for rapid trait introgression.

c) Gene editing in combination with Speed breeding for crop improvement: Speed breeding can save the time of generation development by combining it with genetic engineering tools. Gene editing is a technology in which there is editing in the genes of that particular crop species.Gene Editing tools can only edit one or two non-elite genotypes which are passed through a process of transformation and tissue culturing to regenerate the edited plants. In a new method "ExpressEdit" (Figure 1), by combining the speed breeding with Gene-editing tools, most of the in-vitro manipulations have been bypassed. So, it lowers the lab work pressure and is considered time-saving to develop the crop. "ExpressEdit" is carried out by coupling the speed marker-assisted selection and Gene editing tools components with speed breeding which can exclude the sensitive callus culturing step1.

Achievements and case studies of Speed breeding:

By the speed breeding program, growing up to six generations per year is possible in barley, wheat, chickpea, and up to four generations of canola. Speed breeding is also applied in pea, grass pea, peanuts, amaranthus, quinoa, Brachypodium, Medicago, and many other crops. Speed breeding programs can accelerate a rapid generation and also develop the breeding population.

"DS Faraday" a wheat variety was developed through this technique, which is a high protein, milling wheat with tolerance to pre-harvest sprouting (Tarek *et al.,* 2018). Mostly, in wheat plant height, flowering period, and resistance to several diseases can be achieved by speed breeding.

"Scarlett" is the widely cultivated cultivar of barley in Argentina, which is susceptible to many different types of diseases. A resistant line in barley was developed by taking four lines with a modified backcrossing method in two years (Hickey *et al.,* 2017).

"YNU31-2-4", a Salt tolerant variety in rice, was developed with the help of speed breeding. The gene was inserted by a single nucleotide polymorphism marker, and the breeding cycle accelerated by speed breeding by using 14h light/10h dark- germination to 30 days of germination, 10h light/14h dark reproductive phase.

Table 1: Application of Speed breeding techniques toward crop improvement

S.No.	Species	Traits	Reference
1	Chickpea	4-6 Generation/year	Oconnor *et al.*, 2013
2	Barley	Resistance to Leaf Rust	Watson *et al.*, 2018
3	Spring wheat	Resistance to Stem Rust	Riaz *et al.*, 2018
4	Spring wheat	4-6 Generation/year	Watson *et al.*, 2018
5	Barley	4-6 Generation/year	Watson *et al.*, 2018

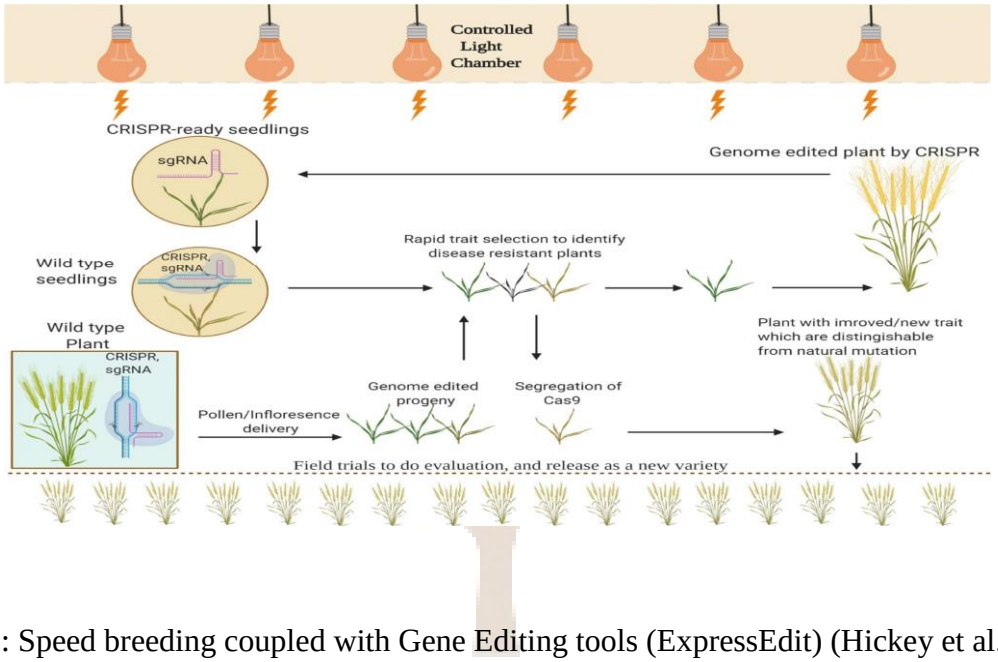

Fig 1 : Speed breeding coupled with Gene Editing tools (ExpressEdit) (Hickey et al., 2019)

Challenges and limitations in speed breeding program

Implementation of speed breeding is the main challenge because precise control of the growing conditions (particularly the photoperiod, temperature, and humidity). Other than this most crops are long day and day-neutral plants hence, continuous light can accelerate the genetic gain and breeding cycle but, the short-day plant required limited photoperiod for their growth and development. Extended photoperiods may cause injury in some crops. The initial investment in speed breeding is high because these programs are carried out in a glass chamber. Other than this, plants that are grown in a glass chamber with extended photoperiod show various physiological and toxicity symptoms like necrosis chlorosis, and yellowing due to any micronutrient or heavy metal deficiency or excess.

Conclusion

As the world population is continuously growing so it will be difficult to overcome food scarcity in the future generation. So, various crop improvement technology and methodology should be developed. But conventional breeding methods are time-consuming, laborious, and untargeted breeding programs. To deal with this challenge and to enhance crop production efficiency speed breeding can be a good alternative. Speed breeding is an innovative approach that can be used to improve crop productivity by creating a variation in the light duration, light intensity and temperature-controlled zone. Speed breeding can be coupled with new technologies like marker-

assisted selection, genomic selection, CRISPR gene editing etc. This type of combination can shorten the breeding cycle, generation advancement and accelerates the development of cultivars in a very short time.

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