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Speed Breeding : Accelerated Plant Breeding

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Abstract

Burgeoning population, ever changing lifestyles and advancing climate change has made it mandatory to revamp the currently available crop cultivars so as to secure food & nutritional security worldwide and accomplish other market driven traits. Although a lot of appreciable work has been done to produce high yielding and nutrient-rich strains of panoply of food and fiber crops, the pace of breeding superior varieties is yet to match the demand for the same. The duration of the seed-to-seed cycle, which is 10-12 years in case of conventional approaches, is one of the crucial bottlenecks in the progress of modern plant breeding ventures. The concept of Speed Breeding serves as a saviour here by drastically reducing the time required for cultivar development, release and commercialization to nearly half. It is a suite of techniques that involves the manipulation of environmental conditions under which crops are grown, aiming to accelerate flowering & seed set and advance to the next breeding generation as quickly as possible. It encompasses manipulation of day/night temperature, available light spectrum & intensity, photoperiod duration, soil moisture, use of PGRs, adjusting CO2 & O2 levels in air and high-density plantings in order to reduce time to floral initiation, hasten embryo development and seed maturity. Recent research has shown the power of combining emerging techniques, such as gene editing using CRISPR/Cas9, high-throughput phenotyping and genotyping, genomic selection, and MAS, with SB for boosting genetic gain. There are few key challenges limiting the deployment of speed breeding techniques in developing countries, including the high costs of infrastructure, required expertise & skill set and continuous financial support for research and development to maintain this as a sustainable operation. However, the existing constraints can be resolved by further optimization of the SB protocols for critical food crops and their efficient integration in plant breeding pipelines. Collaborative international research endeavours involving multi-disciplinary teams are needed to encourage the integration of SB systems in basic and applied research. Nonetheless the technique of Speed breeding will come out as the next breakthrough of the century and become the part and parcel of modern breeding manoeuvres.

Key words : Speed breeding, controlled environment, genetic gain, genomic selection.

Agricultural transformation is of utmost importance for development of a nation as a whole, requiring cutting edge multidisciplinary research and implication of off-the-shelf

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technology at farm level. The need of superior plant varieties with high yield and quality product has been a major driving force in modern plant breeding ventures and will continue to be the same in coming future. Although remarkable achievements have been made by the diligent efforts of plant breeders throughout the world, the pace of development of such novel plant varieties is unable to match the demand for the same. The reason behind this is the lengthy breeding cycle required for progression a potential entry to its release as a plant variety. Conventional plant breeding methods require considerable time (usually 8-10 years) and labour in terms of strategic crossing and subsequent selection of desirable plant type. The technique of Speed breeding serves as a saviour in this situation, as it substantially reduces the breeding cycle, accelerating the scale and speed of crop improvement.

The term ‘Speed breeding’ was coined by researchers in the University of Queensland in 2003 where the concept emerged after being inspired by NASA’s technology of raising wheat variety ‘USU-Apogee’ in space station with constant light. In 2017, the University of Queensland, Australia produced the first speed-bred spring wheat variety, named 'DS Faraday'.

Speed breeding is a series of tactics that involves manipulation of the environmental conditions in which crops are raised with the goal of speeding up flowering & seed set and to proceed to the next breeding generation as soon as possible. Notable techniques existed earlier like doubled haploid (DH) production and shuttle breeding that could decrease the time period of seed-to-seed cycle but speed breeding apexed them all by virtue of its precision and flexibility to be combined with other advanced breeding tools like MAS, genomic selection, high throughput genotyping & phenotyping, gene editing using CRISPR/cas9 and so on.

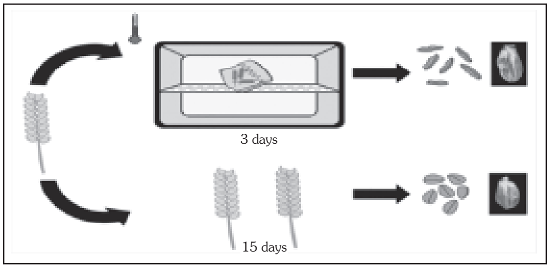

Fig. 1. Speed breeding employs harvesting of pre mature seed and artificial drying to reduce the time period.

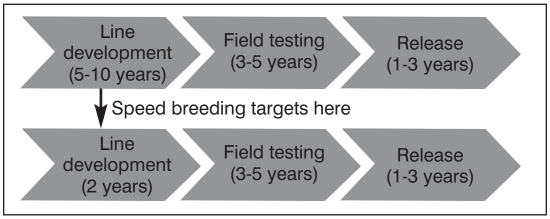

Fig. 2. Timeline of conventional and speed breeding (Samantara *et al.*, 2022)

The Core Manipulations

Speed breeding (SB) relies mainly on manipulation of day/night temperature, available light spectrum and intensity, photoperiod duration, humidity regime in order to reduce time to floral initiation, hasten embryo development and seed maturity. The major manipulation involves:

a. **Photoperiod :** The length of daily exposure of plants to scheduled light and dark regimes that facilitates rapid growth, development, flowering, and seed set is referred to as photoperiod. Light can be manipulated in terms of light quality, intensity and photoperiod with help of LED lights or other artificial illuminating sources that differ from crop to crop in order to trigger flower initiation and further development. When compared to wheat genotypes produced with 12/12 hr light/dark, it was observed that a photoperiod of 22 hr light and 2 hr dark under PAR of 150–190 µE m^{-2} s^{-} reduced the total number of days to flowering to half (Dubcovsky *et al.*, 2006).

b. **Temperature regime :** Low and high temperature extremes trigger a variety of consequences on plant development, including the transition from vegetative to reproductive stages (McClung *et al.*, 2016). Indoor speed breeding programmes in developing nations can utilize solar/battery-powered air-conditioning systems, which would be a cost-effective and reliable technology. For germination of direct seeded immature seed in chickpeas, temperatures of 25 ± 1 °C maintained under a 12/12 hr light/dark cycle gave satisfactory results (Samineni *et al.*, 2019).

c. **Soil moisture :** Soil moisture stresses can modify plant growth and development processes, influencing plant height, flowering days, and seed set and maturity. Drought or flooding stress can be exploited in speed breeding to trigger early flowering and maturation. In cowpea, plants grown under drought stress flowered about 12 days earlier than those grown under well-irrigated conditions (Agbicodo *et al.,* 2009). Reducing the irrigation frequency from daily to twice per week, from four to six weeks after flowering followed by no irrigation in the pre-harvesting week has been used in speed breeding of several crops including wheat, barley, canola and chickpea. (Watson *et al.*, 2018).

d. **CO_2 concentration :** In some plants, higher levels of carbon dioxide (CO_2) may speed up plant growth and accelerate the shift from the vegetative to reproductive stages (Jagadish *et al.*, 2016). This modification can be done in growth chamber using CO_2 cylinders and regulators. However, safety guidelines must be followed while working out such tasks. Days to flowering in soybean, rice and cowpea were reduced by 2, 7, and 12 days, respectively, when CO_2 levels were increased to 400/700, 350/700, and 350/650/100 ppm (Springer & Ward, 2007).

e. **Planting density :** High planting density is a low-cost speed breeding strategy that allows for rapid generation advancement while retaining the large population size needed for advanced selections. Because of light competition, high plant densities result in tall plants, causing a quick shift from vegetative to reproductive growth stages (Warnasooriya & Brutnell, 2014). In rice, up to four generations per year were achieved using a high-density planting of 400 plants m^{-2} (Rahman *et al.*, 2019).

f. Use of PGRs and nutrition: Plant growth regulators and nutrition have been used to induce germination of immature seed in vitro, expedite flowering and seed set. Increased seed set was achieved by exogenous application of 6-benzylamino-purine (10-5 M BAP) four days after flowering in faba bean (Mobini *et al.*, 2020).

Watson *et al.* (2018) proposed a set-up of speed breeding in wheat crop which requires photoperiod of 22 h provided by white LED bulbs, far-red bulbs, ceramic metal hydrargyrum quartz iodide bulbs where the intensity of light was set to 360–380 µmol m^{-2} s^{-1}; 2 h of darkness; 22°C day/17°C night temperature and 70% relative humidity. When grown under these conditions, wheat flowered in half the time of controls grown in unregulated glasshouse conditions.

Studies showed that by using speed breeding techniques in specially modified glasshouses, six generations of wheat, chickpea and barley plants, and four generations of canola plants can be raised in a single year as compared to two or three generations in a regular glasshouse, or a single generation in the field. It was also observed that the quality and yield of the plants grown under controlled climate and extended daylight conditions was as good, or sometimes better, than those grown in regular glasshouses.

Challenges and Future Prospects : Speed breeding is a phenomenal technique for accelerating crop improvement programmes. One of the best features of SB set up is its flexibility to combine with high throughput breeding tools such as MAS and Genomic selection. Since it can substantially reduce generation intervals, genetic gain from this approach could be greatly increased by applying genomic selection at each generation to select the parents for the next generation (Hickey *et al*., 2019). However, the technology requires expertise, effective and complementary plant phenomics facilities, appropriate infrastructure and continuous financial support for research and development. Integrating genome editing and speed breeding without tissue culture requires a number of technological breakthroughs. The existing restrictions, on the other hand, can be overcome by further optimising SB methods for essential food crops and ensuring their efficient incorporation into plant breeding pipelines.

Conclusion

By reducing the time and space invested in the selection and genetic progression of superior crop varieties, speed breeding can hasten the development of high-performing cultivars with market-preferred traits. Rapid generation advancement will open up a wide range of possibilities to assess the phenological responses of genotypes and modify them in favour of human needs. When combined with biotechnological tools like genomic selection and plant tissue culture techniques, it will enable the breeders to produce superior genotypes keeping pace with changing environment and ever-increasing human population.

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