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SPEED BREEDING: A REVOLUTION IN MODERN PLANT BREEDING

S. Mudhalvan*, A. Vijay, G. Gowthaman, K. Rajasekaran and K. Saravanavel

Department of Agriculture, KSAH, Kalasalingam Academic of Research and Education, Krishnankoil - 626 126, Tamilnadu, India.

*Corresponding author E-mail : muthalvanshanmugam2012@gmail.com

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ABSTRACT

Speed breeding is an innovative agricultural approach that accelerates plant growth cycles under controlled environmental conditions, enabling multiple generations of crops to be produced within a single year. This technique integrates extended photoperiods, optimized temperature regimes, and controlled environments such as greenhouses or growth chambers to significantly reduce generation time. The role of speed breeding in crop improvement is profound, as it enhances the efficiency of plant breeding programs by rapidly advancing generations, facilitating quicker selection of desirable traits, and shortening the time required to develop new varieties. When combined with modern tools such as genomic selection, marker-assisted breeding and gene editing, speed breeding enables faster incorporation of traits like high yield, disease resistance, climate resilience, and improved nutritional quality. It also supports pre-breeding and research activities by accelerating genetic studies and trait validation. Overall, speed breeding represents a transformative strategy to meet the growing global demand for food security by expediting the development of superior crop varieties in the face of climate change and population growth.

Key words : Speed breeding, Crop improvement, Phenotypic and Genetic assessment.

Introduction

Plant breeding has had a significant impact on global food production since the early 1900s and has been essential to guaranteeing food security and safety (Tester and Langridge, 2010). However, as a result of the overwhelming food requirements for the fast-growing human population, issues with food quantity and quality have emerged globally in recent years. Additionally, heat and drought stress are being brought on by drastic weather fluctuations brought on by global climate change; as a result, farmers worldwide are experiencing large production losses (Von Braun *et al.*, 2005). Food manufacturing departments are under more strain as a result of developed nations' greater agricultural production, which partially satisfies their food needs (Voss-Fels *et al.*, 2019). Plant with desired characteristics can be developed through plant breeding (Cheema, 2018). For the past 10,000 years, mankind has utilized artificial plant selection to choose and develop plants with superior nutritional contents (Moose and Mumm, 2008). The current level of annual yield enhancement in key crop

species (which ranges from 0.8 to 1.2%) needs to be doubled in order to meet the steadily rising demand for plant-based products (Li *et al.*, 2018).

Various strategies have been employed to reduce the length of plant reproductive cycles. Plant breeding has been demonstrated to be accelerated by new methods created in this decade, including genomic selection, high-throughput phenotyping (HTP) and current speed breeding. Using gene transformation, genetic engineering and molecular techniques have also contributed to the development of crops with desired traits (Majid *et al.*, 2017).

Methods of speed breeding utilization in breeding programme

Even though this chapter covers a wide range of techniques for reducing generation time, their use is still restricted for some crops, such as sugar beet, which has a biennial life cycle. Researchers have shown that adding genes that promote rapid blooming can speed up the generation of inbred lines in this species. Under continuous light conditions (24-hour photoperiod), the *Bd* gene causes

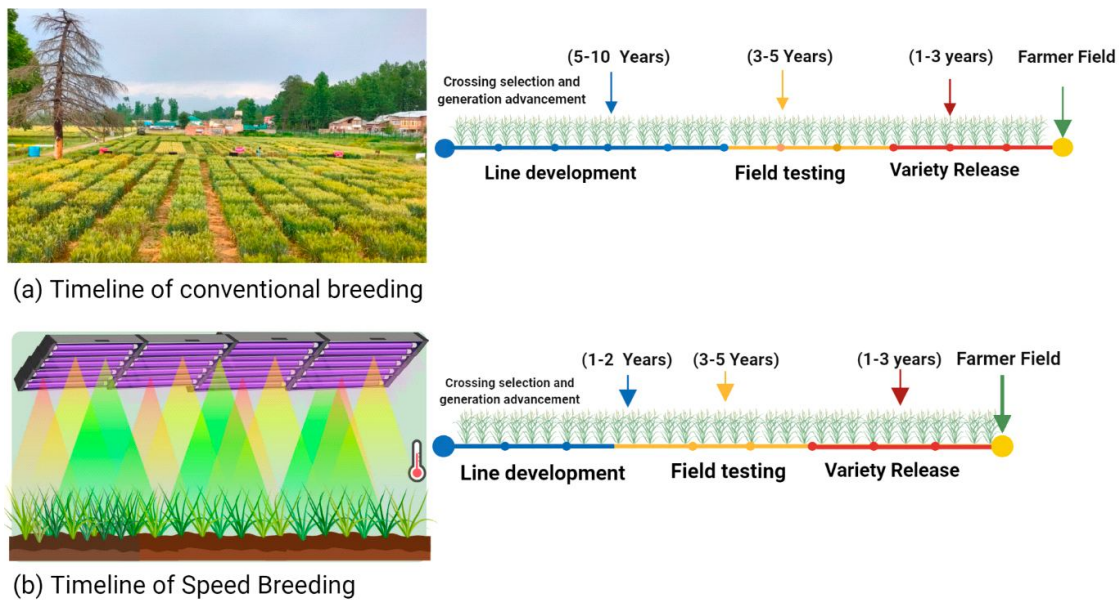


Fig. 1 : Comparison in Timeline of Conventional and Speed breeding (Samantara *et al.*, 2022).

early flowering without vernalization in sugar beet. In the field, this feature stays dormant, preventing early bolting. Complete plant development can be achieved in four months by including this gene into SB procedures (Kroupin, 2024). The kind of viral vector and the particular FT homolog employed determine the method's effectiveness; heterologous FT genes are more successful since they lessen the RNA silencing of endogenous genes (Deng *et al.*, 2024).

Practical application of the speed breeding

Speed breeding (SB) is a popular and widely used technique in plant breeding, genetics, and other areas of plant research because of its benefits, which include rapid plant vegetation, an accelerated transition to the next generation in shorter timeframes, synchronized flowering, the formation of viable seeds, and the ease of use and affordability of the developed protocols.

Hybridization and segregation of hybrids into lines

Flowering synchrony within a single genotype and across many genotypes is made possible by SB circumstances (Watson *et al.*, 2019). Many crossings, particularly those in remote hybridization, are made possible by the SB's capabilities. These circumstances result in a high seed set and strong germination of the hybrid seeds that are produced (Marenkova, 2024). Under SB conditions, seed germination and the timing of phenological stages do not change from generation to generation. Molecular markers can be used to confirm hybridity when obtaining F_1 hybrids (Mobini *et al.*, 2016). F_1 hybrids created by crossing a father genotype carrying a dominant trait with a maternal genotype carrying a

recessive trait can also be evaluated phenotypically (Edet and Ishii, 2022). The SSD approach is perfect for separating hybrids into pure lines in SB conditions. Following hybridization, the process usually entails producing a high number of F_1 hybrid seeds in the second growth cycle, transplanting all of the seeds (250–1000 plants) in the third growth cycle, and then replanting one seed per plant over three to four cycles. Rapid and extensive line generation is made possible by this technique for both genetic research and breeding evaluation (Ficht *et al.*, 2023).

To prevent bottleneck circumstances, no parallel selection is done when establishing recombinant inbred lines for genetic research. On the other hand, selection based on phenotypic variables that demonstrate a high link between SB and field conditions may be used to produce breeding lines. Modern digital phenotyping techniques can be used in addition to traditional phenotyping, which is done visually or by manually measuring several plant properties. Genotyping can also be used for plant selection and culling in segregating populations (Watson *et al.*, 2019).

Genomic selection

When compared to conventional techniques, genomic selection is one of the most promising approaches. Due to recent developments in affordable, high-throughput SNP chips and NGS-based platforms for genotyping large segregating populations, this strategy is becoming more and more realistic for breeding (Li *et al.*, 2018). The main benefits of genomic selection are its high breeding efficiency for quantitative traits (such yield and disease resistance) that are controlled by several loci, each of

which has a little impact on trait expression. Due to the difficulties of phenotyping, these quantitative features are usually assessed later in the breeding process, therefore genomic selection provides an extra advantage (Watson *et al.*, 2018)

Evaluation of plant resistance to pathogens

Plant resistance to several diseases under SB and in the field after artificial inoculation is strongly correlated, according to numerous experiments. For instance, there was a strong association between field-based measures and the disease response to leaf rust seen in wheat plants grown under SB (regression analysis, $R^2 = 0.77$) (Riaz *et al.*, 2016). Fusarium head blight (FHB) and yellow spot (YS) in wheat showed similar outcomes: phenotypes evaluated under SB and field settings showed a good association (Dinglasan *et al.*, 2016).

Evaluation of phenotypic expression of agronomically valuable traits

Selection based on the majority of phenotypic traits cannot be carried out as in traditional field breeding in the SB, which mainly features environmental elements atypical of field circumstances. For example, experimental data indicates that features like wheat awn length and spikelet quantity per spike do not correlate with SB (Cha *et al.*, 2023). Nonetheless, some characteristics that are expressed under SB show a strong association with field performance, allowing for efficient selection in the accelerated development system. Furthermore, plant trait expression is constant and unaffected by weather variability because SB provides stable growing conditions across generations (Watson *et al.*, 2018). Preliminary experiments are carried out employing contrast collections that show differential expression of desired traits in order to assess the viability of trait selection under SB. These studies contrast multi-year field data with phenotypic performance under SB (Hickey *et al.*, 2017).

Steps involved in speed breeding

The process of speed breeding entails establishing ideal growing circumstances for plants in regulated settings in order to hasten their development. The essential elements of the fast-breeding procedure are outlined in the following steps:

- **Plant Material Selection:** Select the desired crop or plant species for fast breeding enhancement. Think about the particular objectives, characteristics, and difficulties related to the target crop (Ahmar *et al.*, 2020).
- **Establish a controlled environment,** such a greenhouse or growth chamber, where

environmental variables can be accurately controlled. To establish ideal circumstances for plant growth, regulate lighting, temperature, humidity, and nutrition levels. (Ragaveena *et al.*, 2021).

- **Illumination Manipulation:** To increase photosynthetic activity and prolong the photoperiod, use artificial illumination. Utilize light sources with certain spectra that encourage plant growth and development, such as high-intensity light-emitting diodes (LEDs) (Paradiso and Proietti, 2022).
- **Control of Temperature and Humidity:** To establish ideal growing conditions for plants, maintain ideal levels of temperature and humidity. Depending on the desired crop and its growing requirements, these circumstances could change. (Chaudhary *et al.*, 2011).
- **Preparing and Planting Seeds:** Make sure the seeds are viable and of high quality before planting them. To improve germination rates and uniformity, treatments like scarification, stratification, or Priming may be used. Plant the seeds in trays or suitable growth media. (Afzal *et al.*, 2016).
- **Crop Management:** Throughout the crop's growing cycle, keep a close eye on it. This includes fertilizing, watering, and shielding the plants from illnesses and pests. To maximize plant growth and development, keep the growth environment constant. (Lutaladio *et al.*, 2009).

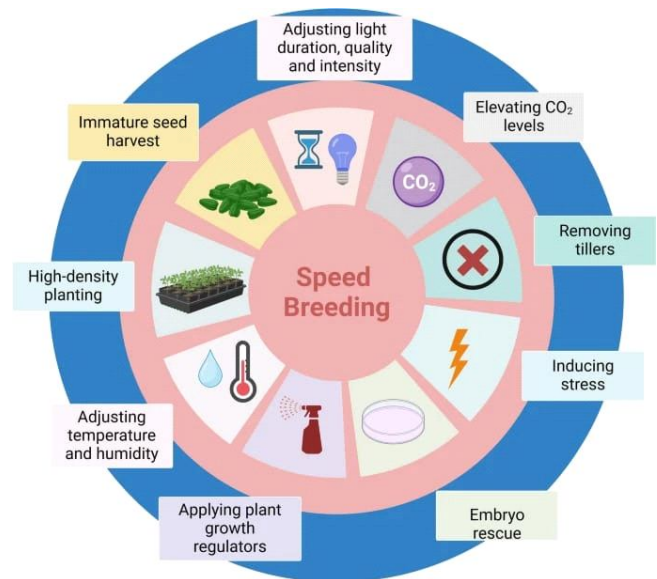


Fig. 2: Main speed breeding components and their utilization in plant research (Aggarwal *et al.*, 2025).

- Accelerated growing Cycle: Modify the growing circumstances to shorten the time needed for each plant generation in order to speed up the breeding process. Reduce the length of the vegetative and reproductive stages by modifying the temperature, illumination, and availability of nutrients. This enables several plant generations to occur in a single year.

Speed Breeding (Time-saving Tools) for accelerating Plant breeding

Technologies to speed up plant development and generation turnover are required because the majority of plant species impede their applicable research and breeding activities. All plant scientists were inspired by NASA's efforts in the early 1980s. The phrase "speed breeding" was first used in 2003 by researchers at the University of Queensland to describe a set of techniques designed to speed up wheat breeding. Several crops are presently undergoing the development of speed breeding techniques (Watson *et al.*, 2018). Unlike doubled haploid (DH) technique, which produces haploid embryos to provide totally homozygous lines, speed breeding is appropriate for a variety of germplasm and does not require specialized equipment for *in vitro* culturing (Slama-Ayed *et al.*, 2019). The idea behind speed breeding is to shorten the generation time by using annual seed harvesting in conjunction with optimal light intensity, temperature, and daytime length control (22 hours of light, 22 °C Day/17 °C night, and high light intensity) to increase the rate of photosynthesis, which directly stimulates early flowering. (Watson *et al.*, 2018). The control of flowering is largely dependent on the wavelength and intensity of light (Weller *et al.*, 2001). We developed early- and late-flowering genotypes for peas, chickpeas, faba beans, and lupins under controlled conditions using various parts of the light spectrum (blue and far red-improved LED lights and metal halide). The declining red: far red-red percentage (R:FR) was positively correlated with these species. Consequently, the most inductive light in the FR area has the most power (Ribalta *et al.*, 2017). Generally speaking, light with a high R:FR (from fluorescent lamps, for example) decreases stem enlargement and boosts lateral branching, while light with a low R:FR (from incandescent lights, for example) significantly increases stem elongation but prevents lateral branching and flowering. FR controls this activity, and phytochrome FR (Pfr) is mediated by blue light. Additionally, phytochrome R (Pr) mediates the action of R light on flowering suppression (Moe *et al.*, 1990). Certain environmental cues, such short days or vernalization like RGA, have been used in species-specific protocols to trigger early

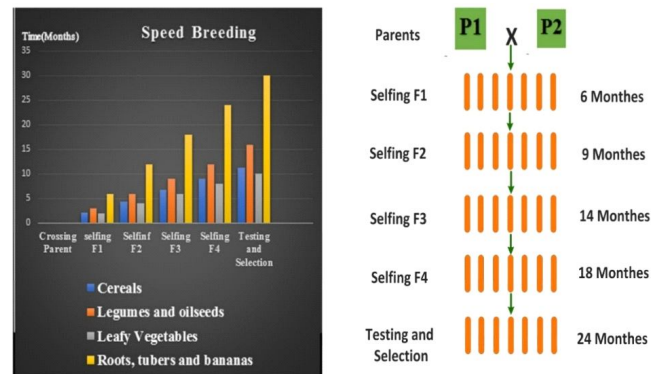


Fig. 3 : Comparison of the amount of time (measured in months) needed to create elite lines for cereals, legumes, oilseeds, leafy vegetables, roots, tubers and bananas (Watson *et al.*, 2018).

blooming (Samineni *et al.*, 2019). Fast generation cycle by prolonged photoperiod and greenhouse tactics under controlled settings were contrasted with *in vitro* and *in vivo* strategies (Ochatt *et al.*, 2002). Compared to the creation of DHs, speed breeding can be used to create repeated generations of enhanced crops for field testing using SSD at a lower cost. Gene insertion (common haplotypes) of diverse phenotype.

Futures of Speed Breeding

Even if conventional methods are still used in current plant breeding, new methods will surely improve its efficacy and efficiency. We can anticipate the development of a variety of methods utilizing multidisciplinary principles in the future to enhance their advantages. To maintain the diversity of our food, Fibre, and biobased economy, crop production strategies, breeding techniques, field testing methodologies, genotyping technology, and even facilities and equipment must be applied across crop species. Plant breeding and cultivation have undergone a sea change since the discovery of CRISPR/Cas9, CRISPR/Cpf1, base-editing, and RGA, which have transformed molecular biology and its creative uses in agriculture. In a mechanism known as "gene drive," GMOs can positively spread a selected gene throughout natural populations.

All things considered, CRISPR-based gene drive systems will eventually prove advantageous to humanity. For example, as plant cultivars resistant to insect pests and pathogens and tolerant to herbicides are developed, they will curb the spread of invasive species, avoid epidemics, and enhance agricultural practices. Speed breeding can help improve current genome editing methods (e.g., CRISPR/Cas9 could knock out genes responsible for late blooming). In order to produce transgenic seeds as soon as feasible, the transgenic plant might be grown under speed breeding circumstances

instead of the typical glasshouse settings following the successful transfer of Cas9 into the plant. Stable homozygous phenotypes can be obtained with this strategy in less than a year. Additionally, since it often takes many years to develop a GMO crop, this strategy also reduces generation time. However, a shift in the pace of genetic gain could result from more effective breeding techniques that combine both technologies. CRISPR/Cas9, which is based on speed breeding and genome editing, will therefore probably become more common. It will be an essential method to acquire plants with certain desired characteristics and help us achieve our global zero-hunger goals. Innovation development is frequently applied to a small number of significant economic crops, which call for particular modifications to the method of reproduction and propagation as well as the “process” of the new line development for the different crops of interest.

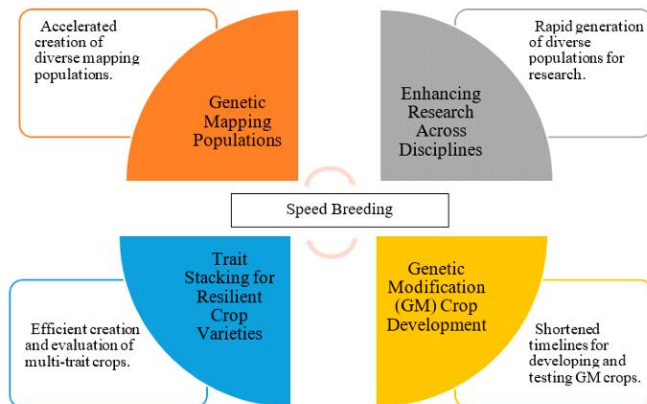


Fig. 4 : Speed Breeding for Crop Improvement and Food Security (Potts *et al.*, 2023).

Conclusion

Since the protocols rely on controlled factors like photoperiod, light source characteristics (including intensity and spectral composition), temperature regimes, substrate volume, application of plant growth regulators, carbon dioxide supplementation, mechanical tiller removal, optimized mineral nutrition, vernalization, and cold stress treatments, speed breeding is a relatively new technique that has garnered widespread recognition and interest among scientists. This is primarily due to its simplicity. This technology has shown itself to be easy to use, affordable and incredibly versatile. The technique’s adaptability has allowed it to be used in a wide range of research fields, such as hybridization and the subsequent segregation of hybrids into pure lines, genomic selection processes, evaluation of plant resistance to pathogens, targeted gene introgression, assessment of phenotypic expression in agronomically significant traits, basic research in plant genetics and cytogenetics,

biotechnological applications, and numerous specialized experiments ranging from photobiological research to agrochemical testing and physiological investigations.

Speed breeding involves more advantages in Rapid generation advancement, faster crop improvement, development of disease-resistant varieties, climate-resilient crop improvement, breeding of high yield varieties, seed production efficiency, supports modern techniques, reduce breeding cycle time and improve food security compared to conventional breeding.

References

- Afzal, I., Rehman H.U., Naveed M. and Basra S.M.A. (2016). Recent advances in seed enhancements. *New challenges in seed biology-basic and translational research driving seed technology*, 47-74.
- Ahmar, S., Gill R.A., Jung K.-H., Faheem A., Qasim M.U., Mubeen M. and Zhou W. (2020). Conventional and molecular techniques from simple breeding to speed breeding in crop plants: recent advances and future outlook. *Int. J. Mole. Sci.*, **21**(7), 2590.
- Araus, J.L., Kefauver S.C., Zaman-Allah M., Olsen M.S. and Cairns J.E. (2018). Translating High-throughput Phenotyping into Genetic Gain. *Trends Plant Sci.*, **23**, 451–466.
- Ausín, I., Alonso-Blanco C. and Martínez-Zapater J.M. (2005). Environmental regulation of flowering. *Int. J. Dev. Biol.*, **49**, 689–705.
- Cha, J.-K., Park H., Choi C., Kwon Y., Lee S.-M., Oh K.-W. *et al.* (2023). Acceleration of wheat breeding: enhancing efficiency and practical application of the speed breeding system. *Plant Methods*, **19**, 118.
- Chaudhary, D., Nayse S. and Waghmare L. (2011). Application of wireless sensor networks for greenhouse parameter control in precision agriculture. *Int. J. Wireless Mobile Networks (IJWMN)*, **3**(1), 140-149.
- Cheema, K.S.K. (2018). Plant Breeding its Applications and Future Prospects. *Int. J. Eng. Technol. Sci. Res.*, **5**, 88–94.
- Chiurugwi, T., Kemp S., Powell W. and Hickey L.T. (2019). Speed breeding orphan crops. *Theor. Appl. Genet.*, **132**, 607–616.
- Dinglasan, E., Godwin I.D., Mortlock M.Y. and Hickey L.T. (2016). Resistance to yellow spot in wheat grown under accelerated growth conditions. *Euphytica*, **209**, 693–707.
- Edet, O.U. and Ishii T. (2022). Cowpea speed breeding using regulated growth chamber conditions and seeds of oven-dried immature pods potentially accommodates eight generations per year. *Plant Methods*, **18**, 106.
- Ficht, A., Bruch A., Rajcan I., Pozniak C. and Lyons E.M. (2023). Evaluation of the impact of photoperiod and light intensity on decreasing days to maturity in winter wheat. *Crop Sci.*, **63**, 812–821.
- Ghosh, S., Watson A., Gonzalez-Navarro O.E., Ramirez-Gonzalez R.H., Yanes L., Mendoza-Suárez M., Simmonds J., Wells R., Rayner T. and Green P. (2018) Speed breeding in growth

- chambers and glasshouses for crop breeding and model plant research. *Nat. Protoc.*, **13**, 2944–2963.
- Heuschele, D.J., Case A. and Smith K.P. (2019). Evaluation of Fast Generation Cycling in oat (*Avena sativa*). *Cereal Res. Commun.*, **47**, 626–635.
- Hickey, L.T., Dieters M.J., DeLacy I.H., Kravchuk O.Y., Mares D.J. and Banks P.M. (2009). Grain dormancy in fixed lines of white-grained wheat (*Triticum aestivum* L.) grown under controlled environmental conditions. *Euphytica*, **168**, 303–310.
- Hickey, L.T., Germa S.E., Diaz J.E., Ziemis L.A., Fowler R.A., Platz G.J., Franckowiak J.D. and Dieters M.J. (2017). *Speed Breeding for Multiple Disease Resistance in Barley*; Springer: New York, NY, USA.
- Kroupin, P.Y., Kroupina A.Y. and Karlov Divashuk G.I.M.G. (2023). Root causes of flowering: two sides of bolting in sugar beet. *Agronomy*, **13**, 2671.
- Li, H., Rasheed A., Hickey L.T. and He Z. (2018). Fast-forwarding genetic gain. *Trends Plant Sci.*, **23**, 184–186.
- Lutaladio, N., Ortiz O. and Caldiz D. (2009). Sustainable potato production. Guidelines for developing countries: *Food and Agriculture Organization*.
- Majid, A., Parray G.A., Wani S.H., Kordostami M., Sofi N.R., Waza S.A., Shikari A.B. and Gulzar S. (2017). Genome Editing and its Necessity in Agriculture. *Int. J. Curr. Microbiol. Appl. Sci.*, **6**, 5435–5443.
- Marenkova, A.G., Blinkov A.O., Radzeniece S., Kocheshkova A.A., Karlov G.I., Lavygina V.A. *et al.* (2024). Testing and modification of the protocol for accelerated growth of malting barley under speed breeding conditions. *Nanobiotechnol. Rep.*, **19**, 808–814.
- Mobini, S.H. and Warkentin T.D. (2016). A simple and efficient method of *in vivo* rapid generation technology in pea (*Pisum sativum* L.). *In Vitro Cell. Dev. Biology-Plant*, **52**, 530–536.
- Moe, R. and Heins R. (1990). Control Of plant morphogenesis and flowering by light quality and temperature. *Acta Hort.*, 81–90.
- Moose, S.P. and Mumm R.H. (2008). Molecular Plant Breeding as the Foundation for 21st Century Crop Improvement. *Plant Physiol.*, **147**, 969–977.
- Ochatt, S.J., Sangwan R.S., Marget P., Assoumou Ndong Y., Rancillac M. and Perney P. (2002). New approaches towards the shortening of generation cycles for faster breeding of protein legumes. *Plant Breed.*, **121**, 436–440.
- Paradiso, R. and Proietti S. (2022). Light-quality manipulation to control plant growth and photomorphogenesis in greenhouse horticulture: The state of the art and the opportunities of modern LED systems. *J. Plant Growth Regul.*, **41**(2), 742–780.
- Potts, J., Jangra S., Michael V.N. and Wu X. (2023). Speed Breeding for Crop Improvement and Food Security. *Crops*, **3**, 276–291.
- Ragaveena, S., Shirly Edward A. and Surendran U. (2021). Smart controlled environment agriculture methods: A holistic review. *Rev. Environ. Sci. Bio/Technol.*, **20**(4), 887–913.
- Riaz, A., Periyannan S., Aitken E. and Hickey L. (2016). A rapid phenotyping method for adult plant resistance to leaf rust in wheat. *Plant Methods*, **12**, 17.
- Ribalta, F.M., Pazos-Navarro M., Nelson K., Edwards K., Ross J.J., Bennett R.G., Munday C., Erskine W., Ochatt S.J. and Croser J.S. (2017). Precocious floral initiation and identification of exact timing of embryo physiological maturity facilitate germination of immature seeds to truncate the lifecycle of pea. *Plant Growth Regul.*, **81**, 345–353.
- Samantara, K., Bohra A., Mohapatra S.R., Prihatini R., Asibe F., Singh L., Reyes V.P., Tiwari A., Maurya A.K. and Croser J.S. (2022). Breeding More Crops in Less Time: A Perspective on Speed Breeding. *Biology*, **11**, 275.
- Samineni, S., Sen M., Sajja S.B. and Gaur P.M. (2019). Rapid generation advance (RGA) in chickpea to produce up to seven generations per year and enable speed breeding. *Crop J.*
- Shimelis, H. and Laing M. (2012). Timelines in conventional crop improvement: Pre-breeding and breeding procedures. *Australian J. Crop Sci.*, **6**(11), 1542–1549.
- Slama-Ayed, O., Bouhaouel I., Ayed S., De Buyser J., Picard E. and Amara H.S. (2019). Efficiency of three haplomethods in durum wheat (*Triticum turgidum* subsp. durum Desf.): Isolated microspore culture, gynogenesis and wheat×maize crosses. *Czech J. Genet. Plant Breed.*, **55**, 101–109.
- Tester, M. and Langridge P. (2010) Breeding technologies to increase crop production in a changing world. *Science*, **80**, 327, 818–822.
- Von Braun, J., Rosegrant M.W., Pandya-Lorch R., Cohen M.J., Cline S.A., Brown M.A. and Bos M.S. (2005). *New Risks and Opportunities for Food Security Scenario Analyses for 2015 and 2050*; IFPRI: Washington, DC, USA.
- Voss-Fels, K.P., Stahl A. and Hickey L.T. (2019). Q&A: Modern crop breeding for future food security. *BMC Biol.*, **17**, 18.
- Watson, A., Ghosh S., Williams M. J., Cuddy W. S., Simmonds J. and Rey M.-D. (2018). Speed breeding is a powerful tool to accelerate crop research and breeding. *Nat. Plants*, **4**, 23–29.
- Watson, A., Hickey L.T., Christopher J., Rutkoski J., Poland J. and Hayes B.J. (2019). Multivariate genomic selection and potential of rapid indirect selection with speed breeding in spring wheat. *Crop Sci.*, **59**, 1945–1959.
- Weller, J.L., Beauchamp N., Kerckhoffs L.H.J., Platten J.D. and Reid J.B. (2001). Interaction of phytochromes A and B in the control of de-etiolation and flowering in pea. *Plant J.*, **26**, 283–294.
- Wolter, F., Schindele P. and Puchta H. (2019). Plant breeding at the speed of light: The power of CRISPR/Cas to generate directed genetic diversity at multiple sites. *BMC Plant Biol.*, **19**, 1–8.
- Zhang, F., Wen Y. and Guo X. (2014). CRISPR/Cas9 for genome editing: Progress, implications and challenges. *Hum. Mol. Genet.*, **23**, R40–R46.