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# Unlocking Crop Potential: Speed Breeding and its Synergies with Modern Breeding Techniques

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**ABSTRACT: The global population is projected to reach 8.5 billion by 2030, 9.7 billion by 2050 and 10.4 billion by 2100, posing a significant challenge to food and nutritional security. Further, malnutrition and climate change factors are exacerbating this challenge. In the past, classical plant breeding methods have played a crucial role in addressing food security however, currently these are not sufficient to meet the food demand of ever-increasing population. Therefore, novel breeding technologies, like speed breeding, offer a promising solution. The key driving factors of speed breeding are manipulation of crop photoperiods, accelerating plant development and reduces generation turn over time. It mainly relies on intense lighting regimes to expedite crop growth while maintaining plant health. Speed breeding allows to take up multiple generations of crops, such as wheat, pea, barley, and chickpea, in a year. This review explores the progress made through speed breeding and its integration with other modern breeding methods to address challenges posed by population growth and climate change. Complementary strategies like shuttle breeding, doubled haploid technology, off-season crops, embryo culture and immature seed germination are also discussed. Overall, speed breeding offers a potential solution to address global food security and climate change challenges by reducing generation time and accelerating variety development.**

**Keywords:** Speed breeding, photoperiod, temperature and generation.

## INTRODUCTION

The global population is projected to reach staggering numbers in the coming decades, posing significant challenges in terms of feeding billions of people and addressing issues related to malnutrition and climate change. With an annual growth rate of 0.84%, the global population is expected to reach 8.5 billion by 2030, 9.7 billion by 2050 and a striking 10.4 billion by 2100 (United Nations, 2022). This population growth has raised concerns about our ability to meet the food requirements of such a vast number of individuals (Borlaug, 2002; Wollenweber *et al*., 2005; Godfray, 2014; Fedoroff, 2015). Malnutrition remains a prevalent issue, with a considerable percentage of infants born with low birth weight, 22% of children under the age of 5 affected by stunting, and significant proportions of the global adult population living with obesity (Global Nutrition Report, 2022). Furthermore, the Food and Agricultural Organization (FAO) reports that hundreds of millions of people faced hunger in 2020 (FAO, 2020). In addition to these challenges, the world is grappling with the crisis of climate change, resulting in rising temperatures, the emergence of new pests and diseases and more frequent and intense droughts and floods (Hoegh-Guldberg *et al*., 2019; IPCC, 2021).

In the past great success has been achieved with classical breeding by way of "Green Revolution" through developing short stature, input responsive crop varieties particularly in wheat and rice. However, now they have proven insufficient to meet the demands of the current population and effectively address the challenges posed by climate change (Khush *et al*., 2005). As these methods are time-consuming, often taking more than a decade to develop and release new crop varieties (Hickey *et al*., 2019). To accelerate genetic gain and ensure global food security, it has become imperative to develop new breeding technologies (Tester and Langridge 2010; Taranto *et al*., 2018). In recent past, technologies like rapid generation advance, shuttle breeding, doubled haploid (DH) found promising to some extent, however the major bottleneck associated with them are crop specific, problems with tissue culture in case of DH, etc. Of late, speed breeding has emerged as a powerful technique to tackle the pressing issues of global food security and climate change. By manipulating the photoperiod of crops, speed breeding allows for a significant acceleration of the breeding process (Ghosh *et al*., 2018). Researchers have developed speed breeding protocols for various crops, enabling the cultivation of multiple generations within a single year (Watson *et al*., 2018; Ghosh *et al*., 2018). Till there are several achievements through speed breeding techniques. This approach expedites the selection of desired traits and the development of climate-resilient crop varieties. Furthermore, speed breeding offers opportunities for exploring genetic diversity and discovering valuable traits that can enhance crop performance (Hickey *et al*., 2009).

The combination of speed breeding with other modern breeding methods hold great promise for further advancements in crop improvement. By leveraging the benefits of speed breeding and integrating it with existing breeding approaches, researchers and breeders can work towards ensuring food security for growing population while addressing the challenges posed by climate threats.

**Earlier approaches to hasten plant life cycle:** As we know speed breeding reduces generation time by manipulating photoperiod (Fig. 1). However, there are some other aspects which speed up the breeding cycle such as shuttle breeding, double haploid technique and off season crops. These other approaches were used in past to advance generation and to fasten breeding cycle.

**Shuttle Breeding:** Process of Shuttle breeding was invented by Norman E. Borlaug in 1968 at CIMMYT Mexico involving growing plant generations in dissimilar locations with different climatic zones. Shuttle breeding not only advance generation speedily but also exposes segregating material to different photoperiods and temperatures resulting in broader adaptation. This method enabled growing two generations in a year and production of photoperiod insensitive and widely adoptable genotypes (Rajaram *et al*., 2002). For instance, in wheat, by using shuttle breeding technique Tanio *et al*. (2006) eliminated late heading plants which are sensitive to photoperiod and confirmed that earliness for heading was closely related to *Ppd* gene. Similarly, Kim *el al*. (2020) developed cold tolerant rice variety Jungmo1022 by crossing Jinbu 31 and Gyodong 23 and advancing generations by growing at Chuncheon and Jinbu sites of Korea. Furthermore, in common bean, by integrating drought tolerance from the common bean Mesoamerican and Durango races as well as within the Mesoamerican race. Urrea *et al*. (2022) developed the drought-tolerant cultivars pinto bean SB-DT2 and tiny red SB-DT3. Between Nebraska and Puerto Rico, they progressed material with extensive temperate and tropical adaptability. However, the main limitations of this method are associated with logistic difficulties especially during seed exchange across different countries, IPR issues (Lenaerts *et al*., 2019; Gobu *et al*., 2020).

**Doubled haploid (DH) technology:** The development of complete homozygous lines from heterozygous parents is possible using the DH technology pioneered by Guha and Maheshwari, 1964 which reduces the time needed to produce homozygous plants compared to conventional breeding methods that use multiple generations of selfing (Germana, 2011). There are mainly two methods from which DH can be produced either *in vitro* or *in vivo*. Through pseudogamy, parthenogenesis, or wide crossing haploid embryos can produce *in vivo*. Androgenesis includes anther and microspore culture whereas gynogenesis involves ovary, ovule flower culture belongs to *invitro* method of DH production (Barnabas *et al*., 1999). In addition, bulbosam technique in barley was also enabled to develop DH lines in wheat. Fusarium head blight (FSB) is damaging disease of wheat, Castro Aviles *et al*., (2020) developed doubled haploid mapping population by crossing AGS 2060 and AGS 2035 and identified 13 QTLs which are resistant to FSB. Khulbe *et al*. (2020) studied double haploid induction in maize using TAILP1 haploid inducer and found out that effectiveness of DH production ranged from 0.14 to 1.87%. In rice, Calayugan *et al*. (2020) created doubled haploid population of a cross IR05F102 × IR69428 and carried out genetic analysis for high grain Zn, Fe and other agronomic traits and identified 23 QTLs. Double haploid population were used to identify yellow rust resistance in wheat by Draz *et al*. (2021). They identified major QTLs for yellow rust resistance in DH population one and two. In maize, *in vivo* haploid induction method were used by Taskin and Bilgili (2022) by pollinating the lines with haploid inducer line stock 6 and developed 20 double haploid lines. Among the different crops massive success has been achieved in rapidly developing DH lines in maize. Hence most of the seed industries relies on DH technique for parental line development process. Nevertheless, this method is efficient in some crops, however there are some limitations of double haploid technique such complexities in haploid production and chromosome doubling in many species (Shariatpanahi *et al*., 2021), some crops not well respond to tissue culture, low haploid induction rate, high cost involved (Molenaar and Melchinger, 2019; Watts *et al*., 2020), high mortality and abnormal plant development (Patial *et al*., 2022).

**Off season crops:** With the help of off-season nurseries, it is possible to grow two generations per year. In this one generation grown in normal season and another in controlled atmospheric condition to hasten the breeding cycle. Florez-Palacios *et al*. (2021) successfully completed two generations of soybean variety advancement using off season nurseries. Off-site summer nursery pattern used by Fang *et al*. (2021) to obtain two generations of soybean per year. However, it is not suitable for large scale. However, there are some constraints of off season crops. Sometimes second crop may be affected by natural calamities. Developments of controlled atmospheric conditions are costly in developing countries.

**Embryo culture:** Olive breeding program can be enhanced with help of *in vitro* embryo culture by Acebedo *et al.* (1997). In tomato, Gebologlu *et al.* (2011) isolated immature embryos of tomato 20, 24, 28, 32, 36 days after pollination and applied various growth hormones and concluded that immature embryos harvested 28 and 36 days after flowering germinated successfully. In sorghum, Rizal *et al.* (2014) followed embryo rescue technique to save the vital embryos and shortened the breeding cycle from 17 weeks to 11 weeks. *In vitro* embryo culture along with single seed decent method were used to obtain four generations per year in case of lentil (Bermejo *et al.*, 2019). They isolated embryos after 15, 18, 21 and 24 days after pollination and cultured on MS media along with different concentrations of BAP. Liu *et al.* (2016) used the embryo culture method to practice the fast generation cycle system for breeding oats and triticale and came to conclusion that it was possible to achieve 6.2–7.4 generations per year in oats and 6.0–7.6 generations per year in triticale under this system. In pea, Ribalta *et al*., (2017) figured out that without exogenous application of growth hormone, growth of embryo takes place 18 days after pollination. Embry culture is easy method to advance the generations of field crops but there are some limitations. This method can’t be used in all crops. Because isolation of embryo from seed is tedious process. Sometimes embryo fails to grow into seedlings. Isolation of embryo, its sterilization is laborious and time taking. This method can’t be used in all crops (Gupta *et al*., 2020).

**Immature seed germination:** Germination of immature seed reduces the generation time in various crops. Bhattarai *et al*., (2009) extracted immature seeds of tomato and successfully cultured on MS medium supplemented with IAA, IBA, $GA_3$ and sucrose. Seed obtained 10 days after pollination were cultured successfully. In case of soybean, immature seed harvesting and drying under artificial condition triggers germination of immature seeds and which can reduce generation time by 24 days, were successfully studied by Carandang *et al.* (2006).

**Other techniques to induce early flowering:** Not only supplementary photoperiod induces early flowering and rapid generation advancement but also other factors such as providing stress to plant, restricting plant growth area, limiting access to nutrients and water makes plants to complete their life cycle early. These factors help to trigger early flowering and rapid generation advancement. Yao *et al*., (2016) achieved five generations of *Brassica napus* per year when plants grown in high temperature, water stress conditions and providing continuous light.

**Why there is need of speed breeding:** As we know we have different methods to hasten plant life cycle but speed breeding is well differentiated from them. In Plant breeding genetic gain have prime importance. Genetic gain is well explained by breeder’s favorite equation. This equation represents length of generation time in denominator. The genetic gain is eventually impacted by the number of generations. Length of generation time is key hurdle to bred improved varieties to combat increasing population and changing climate in recent days.

$\Delta G = (\sigma_a)\ (i)\ (r)/\ L$

Where, ‘ΔG’ is genetic gain, ‘$\sigma_a$’ is additive genetic variance, ‘r’ is selection accuracy, ‘i’ is selection intensity, and ‘L’ is length of generation time (Cobb *et al.*, 2019). After crossing of parents, we have to handle segregating material through different breeding schemes to achieve homozygosity, and then multilocations trials to evaluate the material in different agro climatic zones. This process takes lots of time (Fig.1). By this method, conventional breeding strategies take12-15 years to develop new cultivar and make it available to farmers (Watson *et al*., 2018). Speed breeding basically targets on line development. After crossing two parents and getting $F_1$ generation, with increase in photoperiod and optimizing other conditions it is possible to take upto five to six generations per year. In this way, it is possible to achieve homozygosity in one to two year. By manipulating photoperiod of crop, it is possible to bred variety to feed billions of population and to tackle with changing climate.

**Speed breeding approach:** Utilizing ideal day length, light intensity, light quality, humidity and temperature to promote biomass accumulation, stimulate flowering, and accelerate seed production, speed breeding shortens the crop's generation time. It entails using an extended photoperiod to quicken plant growth after collecting immature seeds and shortening generation time through germination. It uses glasshouse, greenhouse or artificial environment with enhanced lightening regimes to boost flowering in long day plants (Watson *et al*., 2018). Protocols for speed breeding had been standardized in major crops (Table 1).

**Speed breeding status*:*** Speed breeding technique has been standardized in cereals, legumes and oilseeds crops (Watson *et al*., 2018; Ghosh *et al*., 2018). Till today using speed breeding technique, several varieties had been released (Table 2). In chickpea, Gaur *et al.* (2007) demonstrated that three seed to seed generations were possible in a year. They have taken one generation in normal growing season, another in spring season and third one in rainout shelter using artificial 24-hr light by using incandescent bulbs. Seven generations of chickpea in a year were possible with 22 hours’ photoperiod and immature seed germination were well demonstrated by Samineni *et al*. (2022). This speed up varietal development rate in chickpea. Cazzola *et al.* (2020) demonstrated that in pea, the hydroponic system in a growth chamber with controlled temperature, day length, usage of flurpimidol antigiberelin and unlikely seed harvesting can produce five generations in a year. Similarly, in faba bean, Mobini *et al.* (2015) used plant growth hormones to achieve *in vitro* flowering and used immature seed germination technique to achieve seven generations in a year and for lentil eight generations per year. They used flurprimidol, indole-3-acetic acid, and zeatin in faba bean to induce early flowering. In lentil flowering were triggered by flurprimidol, chloroindole, indole-3-acetic acid and with a perlite growth substrate. O'Connor *et al.* (2015) demonstrated that, in peanuts controlled environmental condition, increased photoperiod along with optimum temperature and single seed decent method (SSD), curtailed crop growth period from 145 to 89 days. Mobini *et al.* (2020) used cytokines application along with cold treatments to abridge the crop growing period in case of faba bean (*Vicia faba*). Pigeon pea is short day plant having strict photoperiodic requirements, set its limit to grow single generation per year. Saxena *et al.*, (1996) taken four short duration varieties and harvested their seed 21, 28 and 35 days after flowering to check the germination status of developing seeds and to increase rapid generation turnover. Silim *et al.* (2004) studied the response of different maturity duration of pigeon pea to photoperiod and temperature and found that long duration genotypes were flowered early by 0.001 per day, per hour increase in day length. Single seed decent method with immature seed germination technique were produce 3/4 generations per year, when 35 days old seed were harvested in case of pigeon pea were demonstrated by Saxena *et al.* (2017). Speed breeding technique used to advance $F_2$ population of *Lens culinaris* × *Lens ervoides* with aphanomyces root rot screening protocol. Lulsdorf and Banniza (2018) successfully got five generations per year using optimum growing condition, modified single seed decent method and immature seed germination using gibberellin treatment.

Approaches of speed breeding to curtail crop growth period were used in cereals also. Speed breeding protocols for spring bread wheat (*Triticum aestivum*), durum wheat (*T. durum*), barley (*Hordium vulgare*) and model grass *Brachypodium distachyon* were standardized by Watson *et al.* (2018). They gave 22 hr photoperiod and 02 hr dark period under controlled environment. They recorded anthesis time and concluded that in wheat plant completed first opening of flower in 35-39 days. In case of barley it took 37–38 days to first flower. While it goes to 26 days for heading in *B. distachyon.* They recorded another observation like seed count and seed viability. They concluded that, there is no significant effect on seed count and seed germination under normal and extended photoperiod conditions. Alahmad *et al.* (2018) used speed breeding technique in durum wheat and phenotyped, biparental population of outrob 4 × Caoaroi for several characters such as leaf rust, crown rot, plant stature, root angle and root number. They obtained one complete generation in 77 days. Speed breeding technique used to accelerate oat breeding cycle by González-Barrios *et al.* (2021). With 22-hour photoperiod and early seed harvest they obtained one complete generation in 98 days instead of 114 days in normal condition. Multi trait phenotyping along with speed breeding technology were used in barley for introgression of disease resistance to leaf rust, net and spot forms of net blotch and spot blotch from four donor lines into popular scarlet variety by Hickey *et al.* (2017). Finally, they obtained 12 introgression lines which were resistant to multiple diseases. Oat breeding program were hastened using photoperiod extension and foliar mineral supplement by Heuschele *et al.* (2019). They demonstrated that first opening of flower occurred 15 ± 3 days faster, however there was a 3-fold reduction in seed count and a 2-fold reduction in inflorescence weight under controlled condition. Cha *et al.* (2020) successfully used speed breeding along with under matured grain germination in wheat and concluded that seed harvested 20 days after heading were germinated under *in vitro* condition which reduce generation time considerably.

## TECHNOLOGICAL FEATURES OF SPEED BREEDING

**Photoperiod requirement, Light intensity and quality:** The primary source of energy for plants to complete the photosynthesis process is sunlight. Plants are divided into three categories based on their photoperiod needs: short day, long day, and day neutral plants. Long day and day neutral plants respond in better way for extending photoperiod but not short day plants. Eid *et al.* (2016) studied effect of different photoperiod regimes such as natural day length, extended photoperiod (24 hour) and eight-hour photoperiod (short day) on *Hydrangea macrophylla* and concluded that extended photoperiod causes early flowering in all genotypes. Pineda *et al.* (2020) take into account effect of extended photoperiod on diverse maturity group genotypes of cassava and concluded that extended photoperiod induces early flowering in late maturity genotypes. Speed breeding technique also used in short day crops by using light emitting diodes with enhanced light quality, to hasten early flowering in rice, soybean and amaranths. Jahne *et al.* (2020) achieved advance flowering by 10 and 20 days in amaranths and rice by using far red light, but not in soybean. This states importance of light quality in speed breeding. Legendre and Iersel (2021) used far red light to study various aspects of lettuce and concluded that leaf length, leaf width was ultimately increased which results in increase in photosynthesis. Effect of far red light were broadly studied by Li *et al.* (2023) and demonstrated that by using far red light, the flower budding rate, plant stature, internode length, plant display, and stem diameter of Chinese kale were greatly increased. Along with that, photosynthesis rate also increased.

**Temperature and humidity:** Optimum air and soil temperature are key factors to achieve satisfactory germination, seedling establishment and proper vegetative and reproductive growth. Mcclung *et al.* (2016) concluded that ambient temperature that is not too high and too low were suitable for flowering induction in short day as well as long day plants. Ghosh *et al.* (2018) proved that humidity of 60-70 % were suitable for most of the crops, however those crops, who adapted to dry zones requires less humidity.

**Use of growth hormones:** Growth hormones are involved in a variety of processes, including seed dormancy and germination as well as plant growth. Mobini *et al.* (2020); Cazzola *et al.* (2020) well documented that use of growth hormones such as BAP and flurprimidol antigiberlin helps in immature seed germination.

**Integrating speed breeding with other techniques for yield improvement:** Conventional plant breeding methods are mainly responsible for green revolution. In 1970's period India became self-sufficient in food production due to these methods only. However, these methods have several lacunas. In plant breeding, picking up desirable plant is main activity. But selections in segregating generations are depends on phenotype. This phenotypic selection is misleading due to environmental effect. Traits with low heritability are need to be evaluated in multilocation trials for their precise selections which increase its cost. Conventional breeding methods can be used efficiently by combining it with molecular breeding methods (Fig. 2) such as marker assisted selection. Marker assisted selection can be used to improve yield in many crops, such as in rice (Gouda *et al*., 2020; Mahapatra *et al*., 2020; Sundaram *et al*., 2018), maize (Ribaut and Ragot 2007), Soybean (Fallen *et al*., 2007) and Wheat (Leonova *et al*., 2017; Dubcovsky, 2004). Marker aided selection also used for disease resistance such as in Rice (Swathi *et al*., 2019; Sakthivel *et al*., 2017; Sama *et al*., 2012) and wheat (Liu *et al*., 2020; Anderson, 2007; Bariana *et al*., 2007). However, Marker aided selection can't be used for improvement of QTL with smaller effect and for polygenic traits, because polygenic traits are highly complex in nature and affected by environment in great extent (Holland, 2004).

To fulfill the lacunas of marker aided selection several new selections schemes were evolved such as marker assisted recurrent selection, association mapping and genomic assisted selection. Meuwissen *et al.* (2001) performed phenotyping and genotyping for training population and only genotyping for breeding population to estimate genome estimated breeding values (GEBV), based on this selection efficiency were increased. Next-generation sequencing technologies and accurate phenotyping have made it possible to discover the genetic basis of key features for agriculture. (Varshney *et al*., 2014). In rice genomic selection were used to improve blast resistance (Huang *et al*., 2019). Evaluation of grain filling ability is important characteristics in rice, which were demonstrated by Yabe *et al*., (2018) through genomic selection. Genotyping by sequencing techniques were used for genotyping of wheat (*Triticum aestivum* L.) breeding panels to construct genomic selection models for different traits (Poland *et al*., 2012). Combing genomic selection (GS) with other modern techniques such as speed breeding (SB) will help to increase genetic gain. Speed breeding protocols were already optimized in many crops, which helps to abridge the time require to screen the population (Watson *et al*., 2018). Integration of GS with SB will help to achieve the speed up the procedure of variety release, which provide enhanced genetic gain.

Accurate measurement of different plant traits is key aspect in breeding of novel traits. Plant phenotyping is combination of procedures used to tackle plant growth in precise manner. With availability of improved phenotyping techniques such as thermal imaging, 3D imaging, magnetic resonance imaging, computed tomography and imaging spectroscopy, it is possible to measure any traits of plant (Fiorani and Schurr 2013). Climate change affecting rainfall and temperature in great extent which were considered as measure obstacles in breeding of wheat in Australia. A multi trait based approach developed by Christopher *et al.* (2015) combines phenotyping with speed breeding for promotion of root adaptation in water limited environments. Therefore, speed breeding in combination with high throughput phenotyping will help to address the problem of global food security in future.

Due to the accessibility of genome sequencing facilities, haplotype breeding is gaining attention in plant breeding worldwide. Haplotype is a group of polymorphic SNPs which can inherit together in progeny with minimum recombination (Garg, 2021; Stram and Daniel 2017). Tailor made crops can be prepared by combining desirable haplotypes in genetic background of crops. Haplotype identification is easy when we have sequencing data of large no of lines for a given crop. Beavan *et al.* (2017) defined haplotype concept based on whole genome sequencing data. Desirable haplotypes were identified in various crops. Abbai *et al.* (2019) identified haplotypes for grain yield and grain quality in rice. Furthermore, Chen *et al.* (2019) identified desirable haplotypes for seedling vigour in rice. Similarly, in pigeon pea Sinha *et al.* (2020) identified useful haplotypes for drought tolerance. Furthermore, haplotypes were also identified for disease resistance. Liang *et al.* (2020) identified novel pi21 haplotype for blast resistance in rice by using bulk sergeant analysis and whole genome sequencing. Alkali stress is major issue in rice. Mei *et al.* (2022) used a genome-wide association study along with gene-based haplotype analysis to identify haplotypes for alkali tolerance in rice. In maize, Maldonado *et al.* (2019) identified desirable haplotypes for flowering related traits. Likewise, Maldonado *et al.* (2019) identified useful haplotype Hap LA4 for leaf angle. In wheat, Huang *et al.* (2023) discovered new functional haplotype Pm21(8#) for powdery mildew resistance. Whatever haplotypes were identified; these should be incorporated into genetic background of crop. Introgression of these haplotype takes long time due to lengthy breeding procedures and long generation time of crop. So, this haplotype breeding must be combined with speed breeding to accelerate genetic gain.

Although traditional plant breeding gave excellent varieties till today, however due to continues selection, genetic diversity is declining. In present days, Crisper Cas9 technology in spotlight due to precise editing of nucleotides at specific sites by adding, deleting, altering the sections of DNA sequence. In addition to accuracy in editing, this technique produces transgene-free plants, which can offer a glimmer of hope in the majority of nations where genetically modified crops are prohibited. This technique used to tackle issues due to biotic and abiotic stresses. In rice and wheat, yield loss due to salinity is major issue. Excellent reviews were found in rice (Khan *et al*., 2021), wheat and rice (Nazir *et al*., 2022). In rice, Santosh Kumar *et al*. (2020) used crisper cas9 system to induce desirable mutations in mega rice variety MTU 1010 for drought and salinity tolerance. Zhang *et al*., (2019) used crisper cas9 technique to induce targeted mutations in OsRR22 gene for salinity tolerance, which ultimately results in nine desirable mutants. For grain chalkiness and salinity in rice, Alam *et al*., (2022) used crisper cas9 to obtain mutants and analyze the function of OsbHLH044 gene and found out that, loss of function of OsbHLH044 gene leads to better salinity tolerant and greater chalkiness. Due to multiplexing ability of crisper cas9 system, it is possible to modify many traits at a time (Wolter *et al*., 2019). To avoid the obstacles of plant regeneration in the laboratory, express edit system was combined with speed breeding approach to improve the specific traits (Hickey *et al*., 2019).

## CHALLENGES FOR SPEED BREEDING

**Speed breeding of short day plants:** According to photoperiodic responses plants are classified into short day, long day and day neutral plants. Short day plants flower only when it receives certain period of photoperiod less than critical period in 24 hours' period. Long day plants flower, when it receives certain amount of photoperiod greater than certain photoperiod in 24 hours' period. In case of day neutral plants, they don't give response to photoperiod, they flower irrespective of day length (Thomas, 1996). Speed breeding is easy in long day crops because, it requires maximum photoperiod than critical day length. But in case of short day plant it is difficult. Therefore, short day plants limits speed breeding. However, in some short day plants protocols were already optimized such as Rice (Rana *et al*., 2019; Collard *et al*., 2017), Sorghum (Forster *et al*., 2014), Soybean (Nagatoshi and Fujita, 2019), Pigeon pea (Saxena *et al*., 2017), Bambara Groundnut (Ochatt *et al*., 2002), Groundnut (O'Connor *et al*., 2013) and Grain Amaranths (Stetter *et al*., 2016). But there is lack of genotype specific, crop specific and species specific protocol availability in case of short day crops. In rice, soybean and amaranth, Jahne *et al*., (2019) developed speed breeding protocol using light emitting diodes (LEDs) that allow to modify light quality at specific crop stage. In soybean, they used blue light enriched light spectrum instead of red light which resulted in first flower, 21 days after sowing and maturity in 77 days. In amaranth and rice flowering were achieved 35 and 60 days after sowing.

**Infrastructure and expertise availability*:*** In developed countries there is plenty of resources for modern plant breeding activities. However, in developing countries like India, limited infrastructure is major bottleneck to support modern breeding tools and to bred varieties (Ribaut *et al*., 2010). In recent days' public plant breeding programmes were greatly replaced by private companies due to infrastructure availability in public plant breeding programmes (Lindner, 2004; Delannay *et al*., 2012; Huynh *et al*., 2013). In countries with limited resources, there is a need to build the necessary infrastructure before breeding activities can begin. In addition to infrastructure, skilled labour must be developed to facilitate fast-track research.

**Water and electricity:** Speed breeding facilities require continuous photoperiod to hasten breeding cycle. Photoperiod, humidity and temperature systems consume lots of electricity which increases cost of breeding program (O'Connor *et al*., 2013). Such speed breeding glasshouses should be connected to solar grids to supply continuous electricity.

**Other challenges:** In speed breeding environment, due to continuous photoperiod plants flower early and complete its life cycle before the normal period. However, there are certain limitations of using continuous light such as extended photoperiod induces severe injury in some plant species (Velez-Ramirez *et al*., 2011). Increased photoperiod may result into photo damage to plants along with increased activity of respiration were reported by Ikkonen *et al*., (2022). In some plant species continuous photoperiod alter the content of some biochemical compounds. Kumar *et al* studied that activities of antioxidant enzymes such as superoxide dismutase, catalase, guaiacol peroxidase, malondialdehyde, and proline were increased due to extended photoperiod. Furthermore, there is increased risk of pest and disease attack in controlled environment condition which increases cost of experiment. These are some challenges in front of speed breeding which need to be tackle in due course of time.

In spite of these challenges speed breeding technology spreading worldwide to combat situations of food security and climate change (Table 3).

### Table 1: Speed breeding protocols standardized in major crops.

| Sr. No. | Crop | SD/LD/DN* | Conditions required to achieve speed breeding | Generation time | Number of generations per year | Reference |
|---|---|---|---|---|---|---|
| 1. | Wheat | LD | 22 hrs. light, 22/17 °C temperature and immature seed harvest. | 65.4 | 5.6 | (Watson *et al.*, 2018) |
| 2. | Barley | LD | 22 hrs. light, 22/17 °C temperature and immature seed harvest. | 68.4 | 5.3 | (Watson *et al.*, 2018) |
| 3. | Canola | LD | 22 hrs. light, 22/17 °C temperature and immature seed harvest. | 98.2 | 3.7 | (Watson *et al.*, 2018) |
| 4. | Chickpea | LD | 22 hrs. light, (25 ± 1) °C temperature and immature seed harvest. | 50-52.7 in early maturing accessions 55.4-58.6 in medium maturity accessions | 7, 6.2 and 6 in early, medium and late maturity accesions | Samineni *et al.*, 2020. |
| 5. | Pea | DN | 20 hrs. photoperiod, 21°C/16°C light/dark temp., 500 µM $m^{-2}$ $s^{-1}$ light intensity and hydroponic system. | 68.4 | 5.3 | Mobini & Warkentin 2016 |
| 6. | Faba bean | LD | 20 hrs. photoperiod, 21°C light/16°C dark temperature, $10^{-5}$ M BAP application, | 89 |  | Mobini *et al.*, 2020. |
| 7. | Peanut | DN | 24 hrs. light and 28 ± 3°C max. 17 ± 3°C min. temperature | 89 | 4 | O'Connor *et al.*, 2013 |
| 8. | Lentil | LD | 20 hrs. photoperiod, 100 µM gibberellin application and immature seed harvest | 56 | 5 | Lulsdorf and Banniza 2018. |
| 9. | Canola | LD | 20 hrs. photoperiod, 25/22 (±1) °C, | 62-71 | 5.1-5.9 | Yao *et al.*, 2016. |
| 10. | Oat, Triticale | LD | 20 hrs. photoperiod, 25/22°C day/night temperature, 65/85% day/night RH, *In vitro* culture of immature embryos. | 41-61 | 6-7.6 | Liu *et al.*, 2016 |
| 11. | Rice, Amaranth | SD | 10 hrs. photoperiod (Blue light enriched) and use of light-emitting diodes (LEDs). | - | - | Jahne *et al.*, 2020 |
| 12. | Soybean | SD | 10 hrs. photoperiod (Blue light enriched) and use of light-emitting diodes (LEDs). | 77 | 5 | Jahne *et al.*, 2020 |

*SD: Short day, LD: Long day and DN: Day neutral.

### Table 2: Successfully developed and released varieties through speed breeding techniques (Samantara *et al.*, 2022).

| Crop | Variety | Characteristics |
|---|---|---|
| **Wheat** | Blaise (University of Queensland) | Early maturity, high yield potential and good resistance to foliar diseases. |
| **Pea** | Dark Emperador | A fast-maturing improved yield potential and tolerance to various abiotic stresses, making it suitable for diverse agro-climatic conditions. |
| **Barley** | Speedy | Early maturity, disease resistance, and high grain quality |
| **Canola** | Swift Canola | Improved yield potential, oil content, and tolerance to environmental stresses. |
| **Rice** | Rapid Rice | It exhibits early maturity and improved yield potential. Shorter growing seasons or unfavourable climatic conditions. |
| **Maize** | Express Maize | Fast growth and early maturity |
| **Tomato** | Quick Tomato | Early fruiting and improved disease resistance |

### Table 3: Controlled speed breeding facilities across the countries

| Sr. No. | Centre | Crops Targeted | Location |
|---|---|---|---|
| 1. | International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), | Pigeon pea, Chickpea and Pearl millet | ICRISAT, Hyderabad, India |
| 2. | IRRI South Asia Regional Centre | Rice | ISARC, Varanasi, India |
| 3. | African Orphan Crops Consortium | - | Kenya |
| 4. | West Africa Centre for Crop Improvement | - | Ghana |
| 5. | World Vegetable Centre | Vegetables | Taiwan |
| 6. | Global Pulse Confederation | - | United Arab Emirates |
| 7. | BeCa-ILRI Hub | Grass pea and wheat | Kenya |
| 8. | International Institute of Tropical Agriculture | - | IITA, Nigeria |
| 9. | *PAU-Ludhiana | Rice and wheat | Punjab India |
| 10. | *ICAR-IARI-New Delhi, | Rice and Wheat | New Delhi, India |
| 11. | *ICAR-IIPR, Kanpur | Pulse crops | Kanpur, India |

*Under developmental stage

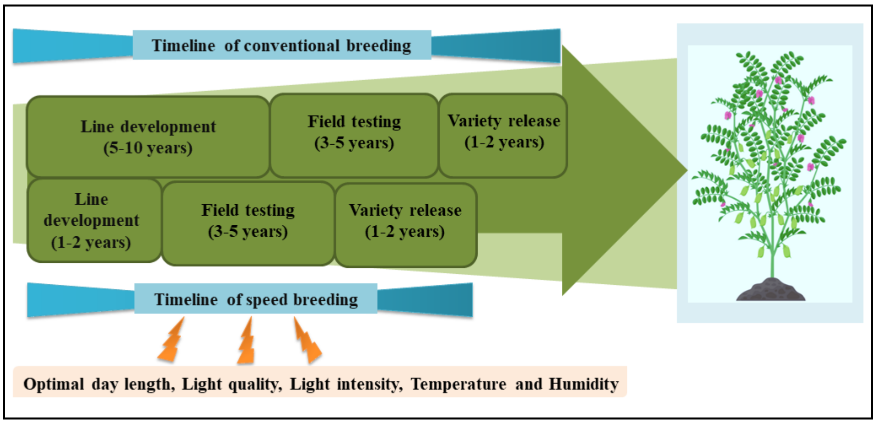

**Fig. 1.** Procedure of variety release through conventional breeding methods compared with speed breeding. In conventional breeding line development takes 5-10 years after crossing of parents. However, use of extended photoperiod along with other controlled environmental condition (light quality, temperature and humidity) reduce this line development period, which hasten the breeding cycle.

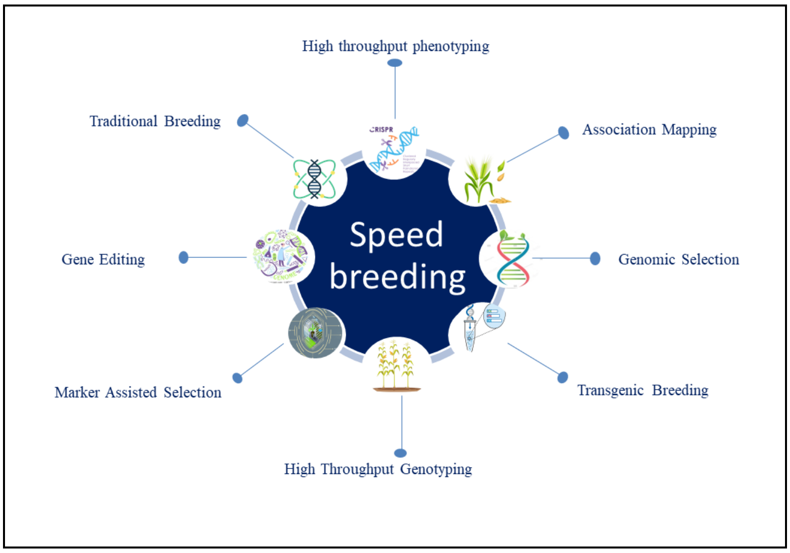

**Fig. 2.** Integrating speed breeding with other modern breeding techniques. When speed breeding combined with other modern breeding techniques such as gene editing, genomic selection, marker assisted selection etc… it improve the selection efficiency along with it reduce genetaion time to release variety.

## CONCLUSIONS

Speed breeding is an important technique to screen thousands of plant population in minimum period and less space to tackle the problems of climate fluctuations and global food security. Due to this technique it is possible to bred several varieties which can withstand in the era of climate change to resist the biotic and abiotic stresses within short period of time. Speed breeding can be combined with other modern breeding techniques such as plant phenotyping, marker assisted selection, marker assisted back crossing, genomic selection, genome editing and express edit to bred climate-smart crop varieties. Speed breeding protocols for short day and horticultural crops need to be optimized. Optimization of speed breeding protocols in neglected crops along with training of personnel for speed breeding are key aspects which need to be focused in future. By using speed breeding with modern breeding tools it's possible to bring second green revolution to feed billions of populations.

## FUTURE SCOPE

Speed breeding techniques must be combined with other breeding technique to improve the genetic gain. Protocols for short day crops need to be optimized in various crops. Crop specific, genotype specific and species specific protocols need to be developed in orphan crops. In horticultural crops, long generation time is major problem to breed new varieties. Therefore, speed breeding protocols for horticultural crops need to be standardized.

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