Temesgen, Adv Crop Sci Tech 2024, 12:3

Advances in Crop Science and Technology

Review Article Open Access

Speed Breeding

Temesgen Begna*

Ethiopian Institute of Agricultural Research, Chiro National Sorghum Research and Training Center, Ethiopia

Abstract

The exponential growth of the human population and increasing climatic change are major challenges to global agriculture because of the need for sustainable food production to feed the growing population. Plant breeding plays a significant role in resolving agricultural problems and enhancing both the production and productivity of the growing population. Breeding new and high-performing cultivars with market-preferring traits takes more than 10 years in the absence of an integrated pre-breeding program. During the early phases of breeding, a significant amount of time, space and resources are invested in the selection and genetic advancement stages after initial crosses are performed with parental genotypes. Speed breeding has the potential to reduce the time required for cultivar development, release and commercialization. Crop improvement in light of the rapidly changing climate and increasing human population continues to be one of the primary concerns for researchers across the globe. The rate at which current crop improvement programs are progressing is essentially inadequate to meet food demand. There is an urgent need for redesigning crops for climate resilience and sustainable yield and nutrition. The rate of crop improvement is largely impeded owing to the long generation time required by crop plants during the breeding process. As a solution in this direction, speed breeding is now being practiced at a large scale to reduce generation time to accommodate multiple generations of crops per year. To enhance the efficiency of breeding, researchers are now adopting an integrated approach in which speed breeding is used along with modern plant breeding and genetic engineering technologies. In the present review, we have summarized the technological aspects, opportunities, and limitations associated with speed breeding. The application of speed breeding, such as mapping population development, haplotype-based breeding, transgenic breeding, and genome-edited line advancement, has also been discussed. Speed breeding is a promising technology that expedites the goals of food and industrial crop improvement by reducing the number of breeding cycles for establishing nutritional security and sustainable agriculture. It is possible to reduce the amount of time needed for developing, promoting, and commercialize cultivars through speed breeding. Ultimately, the rate at which current crop enhancement programs are moving forward is not keeping up with the need for food. Redesigning crops is crucial for long-term productivity and nutrition, as well as climate resistance. The length of time crop plants need to generate throughout the breeding process greatly slows down agricultural progress.

Keywords: Accelerated breeding; Speed breeding; Controlled environment; Crop improvement

Introduction

The increase in the world population coupled with climatic fluctuations such as drought, floods, and high temperatures poses a serious threat to food security (Ray et al., 2013). Many researchers have quoted the importance of enhancing the genetic gain of primary crops at a faster rate to meet global food demands (Lin et al., 2016). It remains a challenging task for plant breeders to evolve resilient varieties in a shorter period by employing conventional approaches. The slow progress in crop improvement is mainly attributed to long breeding cycles/generations (Samantara et al., 2022). To overcome the drawbacks involved in traditional methods and to safeguard food security, speed-breeding methods are now being adopted at large or small units to achieve rapid genetic gains in many crop species. The speed breeding techniques include the use of controlled environments with manipulation provisions for light duration, intensity and temperature. This approach is more advantageous for helping plant breeders hasten crop development in several major photosensitive crops (Singh H and Janeja HS, 2021) [1,2].

Breeding a new crop variety via a conventional approach requires the selection of complementary parental genotypes with desired traits, followed by crosses and a series of selections and advancements of superior progenies to release candidate cultivars that meet market demands (Shimelis and Laing, 2012). Notable breeding goals in crop cultivar development programs include increased yield potential and nutritional quality and enhanced tolerance to biotic and abiotic stresses (Breseghello and Coelho, 2013) [3]. In any crop improvement program, the following breeding procedures can be distinguished in the order presented: (a) selection of desirable parents with complementary traits to be combined; (b) crosses involving the selected parents and the development of progenies; (c) selection and genetic advancement of the best progenies based on target traits; (d) selection of the best progenies for screening in multiple target production environments to identify the best performing and stable candidate cultivars; and (e) cultivar registration and seed multiplication and distribution to growers (Shimelis and Laing, 2012). These conventional breeding procedures are used in most crop cultivar improvement programs. However, conventional breeding procedures can take more than 10 years to develop and release an improved variety in the absence of an integrated pre-breeding program (Ahmar et al., 2020) [4,5].

One major drawback of plant breeding is the long generation time and the ability to grow a single generation per year, which can be alleviated by "speed breeding" with the use of an extended photoperiod and a controlled environment. The world is attracted by the most fascinating technology of speed breeding [6]. The scientist from the

---

***Corresponding author:** Temesgen Begna, Ethiopian Institute of Agricultural Research, Chiro National Sorghum Research and Training Center, Ethiopia, E-Mail: tembegna@gmail.com

Received: 01-March-2024, Manuscript No: acst-24-128578, **Editor Assigned:** 04-March-2024, pre QC No: acst-24-128578 (PQ), **Reviewed:** 18-March-2024, QC No: acst-24-128578, **Revised:** 22-March-2023, Manuscript No: acst-24-128578 (R), **Published:** 29-March-2024, DOI: 10.4172/2329-8863.1000680

Citation: Temesgen B (2024) Speed Breeding. Adv Crop Sci Tech 12: 680.

University of Queensland, inspired by NASA, grew wheat plants in space under artificial light. Watson et al. (2018) successfully developed protocols for different plant species under a speed breeding system. Speed breeding is a powerful strategy for shortening crop generation time and expediting breeding programs for crop improvement (Watson et al., 2018). Speed breeding mimics daily dawn and dusk, and plants are subjected to an extended photoperiod of approximately 22 h by using a combination of different light sources [7]. It provides an extended day length with optimal light intensity coupled with controlled temperature to increase photosynthesis activity, which results in quick flowering and early seed development to reduce generation time (Ghosh et al., 2018) [8].

Speed breeding is revolutionizing agriculture and can accelerate crop-breeding activities such as crossing, backcrossing, rapid gene identification, population mapping, pyramiding of traits, and developing transgenic pipelines (Hickey et al., 2019) [9]. In conventional breeding, only 1-2 generations per season of any crop can be achieved but can be quickly bred up to four generations of B. napus and six generations of Hordeum vulgare, Triticum aestivum, Pisum sativum, Cicer arietinum, and B. distachyon (Watson et al., 2018). Furthermore, it can provide a robust, efficient, and economical platform for carrying out crop improvement projects in an integrated way from genomics to phenomics. It may include candidate gene discovery through GAB approaches such as pangenome assembly, GS, and GBS to multiplex gene editing or metabolic pathway editing for desired traits followed by high-throughput phenotyping to visualize the results [10]. The integration of speed breeding with next-generation metabolomic tools can also be used for rapid risk assessment of gene-edited crops in multiple generations in a robust manner (Razzaq et al., 2019). Hence, speed-breeding technology will offer an exciting way forward for crop improvement by integrating it with next-generation OMICS tools to accelerate crop-breeding programs [11].

The rate of improvement of genetic yield potential has to increase beyond the rates currently achieved in ongoing breeding programs to protect global food security in times of rapid population growth and climate change. Thus, new or different approaches are needed to accelerate the crop breeding process. Over the past few decades, numerous technologies have emerged that can accelerate plant breeding, such as genomic selection. In addition to the genomics approaches, other new methodologies, such as gene editing technology, are fast evolving, and protocols have been refined for most major crop species [12]. In CRISPR gene editing systems, guide RNA directs the Cas9 enzyme to the target DNA site and cuts the DNA. This can be used to activate or deactivate alleles of a target gene to enhance plant performance, e.g., through improving disease resistance or drought tolerance (Liang et al., 2017). Despite the promise of gene editing and strong support from the scientific literature regarding safety and sustainability, many countries have employed strict legal frameworks because of controversial discussions mainly ideology-driven ones and a rejection of genetically modified food [13].

On the other hand, a very widely used and accepted breeding method is mutation breeding, which uses chemicals or radiation to induce random mutations throughout the genome instead of genetically engineered (targeted) mutations. In fact, spontaneous mutations in the plant genome occur naturally [14]. For example, in a wheat field with a size of one hectare, approximately 20 billion mutations occur each year (Prof. Detlef Weigel, personal communication). This is why the majority of the plant science community argues that mutations induced using genome editing where no foreign DNA is introduced should be considered a non-GM tool. Alternatively, 'speed breeding' developed by Dr. Lee Hickey and colleagues provides a non-GM route to rapidly introduce or stack new trait variation. This technique uses controlled environmental conditions and extended photoperiods to achieve up to six generations per year instead of just one or two generations in the field [15].

This approach can accelerate the development of inbred lines following a cross, similar to doubled haploid technology, which is a lab-based technique that has been used for breeding crops such as maize and winter wheat. Most modern technologies have been proven to assist in the development of improved crop varieties [16]. However, more efficient breeding strategies that effectively combine these technologies could lead to a step change in the rate of genetic gain (Begna, 2022). Ongoing investment from the public and private sectors is necessary to build and maintain the capacity for sustained crop improvement to ensure the development of crops that are capable of feeding the world in the future. The objective of this paper was to evaluate potential speed breeding techniques utilized in crop improvement [17].

History and evolution of speed breeding

The development of cultivars requires long generation times and a time-consuming process, and it takes approximately 8-10 years to develop an improved cultivar depending on the breeding procedure and traits of interest. A Long year ago, some scientists and geneticists reported that plants could grow under artificial light with an extended photoperiod to cope with rapid generation cycling and generation advancement. Recently, speed breeding has been introduced, and a majority of more than 100 different plant species, including vegetables, legume crops, cereals and other herbaceous vegetables, have been reported to undergo faster and more rapid generation cycling under continuous light with extended photoperiod conditions [18]. In the 1980s, NASA created a joint research programme with Utah State University for the rapid generation of wheat on space stations, which opened a new era of crop breeding and explored the possibility of growing food in space to meet the requirements of astronauts in space stations. USU-Apogee was the first dwarf wheat variety developed by 'speed breeding' (Hickey et al., 2019) [19].

The discovery of light emitter iodides (LEDs) in the 1990s and their effect on plant growth and development were evaluated at the University of Wisconsin, USA, which has accelerated more advanced research and application of rapid breeding for crop improvement. Inspired by NASA's work, research at the University of Queensland proposed the term "speed breeding" in 2003 to accelerate and rapidly advance wheat breeding. Speed breeding coupled with other technologies, such as double haploid technology and embryo rescue, can shorten generation times (Ahmar et al., 2020) [20]. Speed breeding utilizes continuous supplemental lighting under glasshouse conditions, with an optimum light quantity, light quality, and intensity, and day length accelerates the earlier flowering, photosynthetic rate and rapid generation cycling of crop plants. Generally, different crops respond to different growing environments; hence, it is necessary to design and develop crop-specific standard speed breeding protocols (Velez-Ramirez et al., 2014) [21].

Recently, speed-breeding protocols have been developed for long-day crops but are lacking for short-day vegetables and cereal crops. Moreover, a speed-breeding protocol has recently been demonstrated for several short-day crops, such as Soyabean (Glycine max), rice (Oryza sativa) and Amaranthus (Amaranthus spp.) (Mobini et al., 2015). A speed breeding protocol based on light-emitting diodide

(LEDs) was used; hence, adjusting the photoperiod to approximately 10 hr and increasing the amount of blue light facilitated the growth of short-day crop species such as soybean plants, which flowered 23 days earlier than did normal plants and achieved advanced crop maturity within 77 days, thus facilitating the growth of up to 5-6 generations of soybean per year. Similarly, rice and Amaranthus advanced flowering times of 10 and 20 days, respectively, can be achieved by using a speed-breeding protocol. The first spring wheat variety, "DS Farady", was developed in Australia by using the "speed breeding" protocol [22,23].

Speed breeding techniques

Crop breeding should be accelerated to address global warming and climate change. Breeding initiatives have also successfully addressed global food security concerns, resulting in a doubling of wheat production within 20 years (Curtis, T and Halford N G, 2014). However, the ongoing effects of global climate change necessitate the development of crop varieties that can adapt to changing environmental conditions (Lopes et al., 2015). The generation time of new cultivars is a crucial limiting factor in their rapid development (Ghosh et al., 2018). Traditional breeding methods often take one to two decades to develop a new cultivar, involving processes such as crossing, selection, and field-based testing (Ahmar et al., 2020), as well as a substantial amount of field space and manpower [24] (Figure 1).

Role of speed breeding in the enhancement of crop plants

The majority of plant species have bottlenecks in their applied research and breeding programs, requiring the development of technology to speed up plant growth and generation turnover. NASA's work in the early 1980s was an inspiration for all plant scientists [25]. Researchers at the University of Queensland coined the phrase "speed breeding" in 2003 to describe a set of techniques designed to speed up wheat breeding. Over the last 100 years, traditional breeding programs around the world have produced numerous notable types of improvement. Despite this, development is gradual, in part due to the lengthy breeding cycle, which can take anywhere from 10 to 15 years from cross to cultivar release (Hickey et al., 2017). Combining large numbers of polygenic characteristics is a significant challenge (Breseghello F and Coelho A.S.G, 2013). Although marker-assisted selection has proven to be an effective tool in crop improvement programs, it is most effective at targeting a small number of genes with large effects, such as leaf rust resistance genes (e.g., Lr23) in bread and durum wheat (Chhetri et al., 2017) and Yr15 in durum wheat (Chhetri et al., 2017) [26].

With traditional selection methods, speed breeding produces 3 to 9 generations per year, with 1 to 2 generations per year (Ghosh et al., 2018). As a result, rapid breeding allows for the rapid production of homozygous and stable genotypes, as well as the rapid progress of generations, resulting in the development and release of novel cultivars (Watson et al., 2018) [27]. In addition, for multiple trait selection, speed-breeding technology works well with marker-assisted selection and high-throughput phenotyping approaches. Furthermore, marker-assisted selection may only be used if the target gene or QTL responsible for the desired characteristic is known. As a result, marker-assisted selection is less viable for complex traits when the underlying genetic influences are unknown (Budak et al., 2013) [28].

Genomic selection (GS) has recently surmounted the constraints of marker-assisted selection by estimating breeding values (EBVs), which provide an assessment of the genomic merit associated with all small or substantial impacts across the entire genome using genome-wide markers (Heffner et al., 2009) [29]. Genomic selection also allows for simultaneous selection of several traits; nevertheless, despite the efficiency and promise of this breeding strategy, the costs of genotyping large numbers of selected candidates are currently too costly to encourage widespread usage. Furthermore, because genomic selection is often used for inbred lines (Crossa et al., 2013), the rate of advancement is constrained by the time necessary to conduct crossings and generate new genetically stable selection candidates [30].

Several speed breeding-adapted phenotyping techniques have been established, allowing for the characterization and selection of important traits (Richard et al., 2015). Plant breeders are interested in screening a wide range of traits during early generations of population development. This allows breeding programs to save time and money by reducing labor and field-testing costs [31]. A high-throughput, reproducible, and robust screening methodology is necessary to accomplish this goal. For genetic studies and plant breeding, improving existing phenotyping methods and inventing new methods for phenotyping traits are critical. High-throughput, rapid, cost-effective, and repeatable methods are required for traits that are highly variable not only in the field but also in greenhouses. Speed

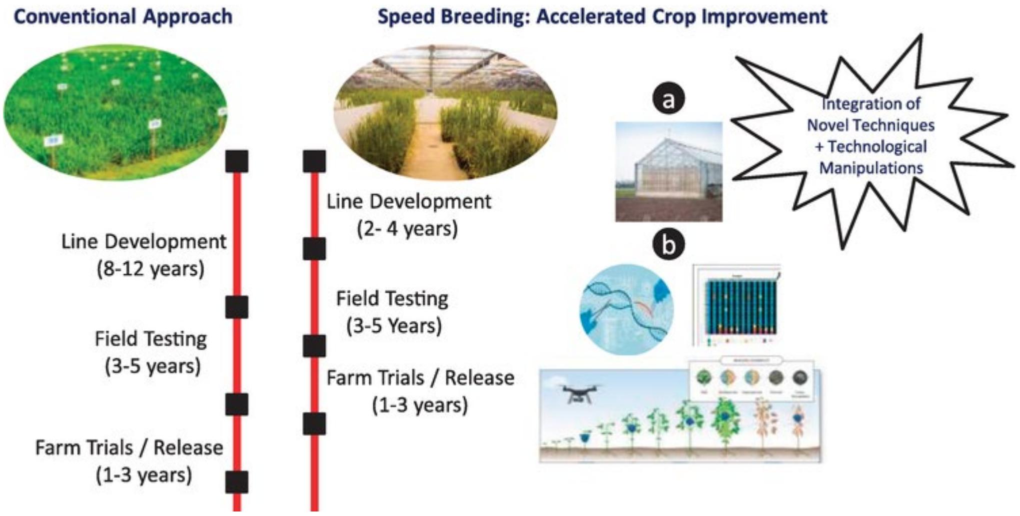

Figure 1: Rapid generational advancement via rapid breeding. a. Crops cultivated experimentally under controlled conditions. b. Using cutting-edge phenotyping tools, high-throughput genotyping platforms, and other contemporary breeding methods in a rapid breeding procedure.

breeding methods can also be used to synchronize the flowering of cultivated and wild individuals of crop species, increasing the amount of variety in breeding populations and accelerating the achievement of breeding goals. Optimizing the plant development environment (plant density, photoperiod, and temperature), genetic engineering targeting the flowering pathway, grafting juvenile plants to mature rootstocks, using plant growth regulators, and harvesting immature seeds are all techniques for rapid cycling (Richard et al., 2015) [32].

Speed breeding to accelerate domestication

Plant domestication is the process of transforming wild plant varieties into crop plants via artificial means. Early hybridization is followed by a selective breeding approach. Plant breeding is especially connected to polyploid crops. It is a time-consuming technique; thus, to address this issue, it has been integrated with speed breeding, which minimizes the duration and number of generations of that crop. Plant domestication proof must be found in polyploid plants such as peanuts and bananas in combination with rapid breeding. O'Connora et al. undertook a study to determine the feasibility of using the speed breeding approach in peanut breeding. In comparison to the regular breeding phase, this study reduced the time it took to produce multiple generations in a shorter period (Hickey et al., 2019) [33].

Multiple disease resistance by speed breeding

Plant breeders are experimenting with new approaches to improve crop production quality to respond faster to changing climates and emerging diseases. Lee T. Hickey et al. (2017) combined the two-row barley cultivar Scarlett with novel approaches for rapid trait introgression. They developed 87 BC1F3:4 Scarlett introgression lines (ILs) in two years using four donor lines with multiple disease resistance and a redesigned backcross method that included phenotypic multi-trait screens as well as fast generation advanced 'speed breeding' technology (Alahmad et al., 2018) [34].

Comparison of speed breeding with other breeding techniques

Plant breeding strategies that use existing genomic variation in plants to generate a variety in eight to ten years can reduce genetic variability in the genome of the plant. Traditional breeding methods cannot meet the ever-increasing food demand for grain crops. It is critical to enhance breeding processes to boost food production in less time. To increase agricultural traits, several conventional and molecular breeding strategies have been applied. CRISPR/Cas9, CRISPR/Cpf1, prime editing, base editing, dcas9 epigenetic modification, and various additional transgene-free genome editing techniques have been created by molecular researchers. These genome editing technologies can precisely and quickly improve desired traits. Furthermore, by reducing the crop cycle, a newly developed breeding technology known as "speed breeding" has transformed agriculture [35,36].

Ensuring global food and nutrition security is an age-old challenge made more difficult by accelerated population growth rates in poor and emerging economies, urbanization, extreme and changing climates, the need to reduce the environmental impact of agricultural activities, and competing demands for food, feed, and fuel (Alexandratos N. and Bruinsma J, 2012). A few and declining number of plant and animal species and strains are being used in global agri-food systems (Khoury et al., 2014) [37]. Shorter breeding cycles (the time between crossing and selecting progeny for use as parents for the next cross) and a reduction in the number of cycles required to develop new varieties can help breeders and researchers make faster progress. In crops such as wheat, rice, and maize, recent improvements in breeding techniques such as genetic engineering, genomic selection, and doubled-haploid technology have shortened breeding cycles and enhanced genetic gain rates. When these technologies are paired with speed breeding techniques, which allow for rapid generation advancement by cultivating plant populations under regulated photoperiod and temperature regimes to hasten their growth and development, they can have an even greater impact [38].

Plant breeding has played a critical role in ensuring food security and safety since the early 1900s and has had a significant impact on the food supply worldwide (Shiferaw et al., 2013). However, in recent years, worldwide food quality and quantity issues have arisen as a result of the excessive food demand for the fast-growing human population. Furthermore, extreme weather changes caused by global climate change are generating heat and drought stress, resulting in major crop losses for farmers worldwide (Von Braun J, 2005) [39]. Global epidemics, such as the Irish potato blight of the 1840s and the Southern corn leaf blight of the 1970s in the United States, were terrible events that killed millions of people owing to a lack of food (Ristaino J.B, 2002). The ratio of food production to consumption has declined significantly in recent years, while worldwide urbanization rates and demographic growth have soared. People choose to consume processed meals, which have a lower nutritional content, in this era of rapid expansion and progress. Traditional farming practices are intended to improve the nutritional value of various food plants. Recent scientific advancements have opened up a wide range of plant breeding options and novelties (Varshney et al., 2006). To meet the growing demand for plant-based products, the current yearly yield enhancement levels in main crop species (ranging from 0.8-1.2%) must double (Li et al., 2018) [40].

Speed-breeding components

Speed-breeding techniques consist of setting up a controlled environment that meets all plant needs and influences plant growth at every stage of development (Ghosh et al., 2018). The basic components of speed breeding include the use of growth chambers with supplemental LEDs for prolonged photoperiods, controlled temperature, and humidity. Environmental factors such as light, temperature, and humidity are important for determining plant growth and health. The optimization of plant growth involves controlling these environmental factors to encourage and boost photosynthesis and vegetative and reproductive growth. In the case of horticulture crops, various technology-driven approaches are employed to grow plants in highly controlled closed environments where various abiotic parameters essential for plant growth can be optimized and maintained throughout development [41].

Light

Light is the source of energy for plant photosynthesis and growth. Light characteristics such as intensity, duration,spectral wavelengths, and direction can influence plant growth and development (Bayat et al., 2018). Lightintensity influences photosynthesis, stem length, leaf color, and flowering (Yoshida et al., 2012). Artificiallight is provided as a photoperiodic light to control flowering and as a supplementary light to reduce plant developmenttime, increase produce quality, and yield (Bergstrand and Schussler, 2013). Runkle and Heins (2001) demonstrated that far-red light promotes flowering in several long-day-old ornamental plants [42]. Petunias and pansies grown under red: blue: far-red light mixtures flower earlier, up to 2 weeks, in plants treated with far-red light than in plants grown without far-red light (Davis and Burns, 2016). The flowering times of beginning and poinsettia advanced in response to red 1 white 1 far-red light treatments (Davis and Burns, 2016). In recent years, the use of LEDs has become an increasingly attractive option for lighting in horticultural systems because of their high radiant efficiency, long life, low heat emission, narrow spectrum, and ability to meet the light intensity and wavelength requirements of different plant species (Bugbee, 2016) [43]. Recent achievements in horticulture with the use of LEDs have been reviewed in detail (Bantis et al., 2018). This review discusses the application and advances of LED light in horticulture to control flowering and increase transplant success, the quality of preharvest, and postharvest produce. The use of LEDs to amend phytochemical content to improve nutritional value in horticultural crops has also been discussed in the above reviews. With a well-established platform, artificial growth could be further optimized to shorten the generation time of horticulture crops. According to the recommendation of Ghosh et al. (2018), any light that produces a spectrum that covers photosynthetically active radiation (PAR: 400 700 nm), consisting of blue, red, and far-red light, is suitable for rapid breeding. LEDs, or a combination of LEDs, can be used to obtain an appropriate spectral range [44].

Temperature

Temperature is a primary factor affecting the rate of plant development. The responses to temperature differ according to plant species and phenological stage (Srivastava et al., 2015). The vegetative growth of plants increases with increasing temperature but is within the required optimum temperature range. In general, in most plant species, the vegetative phase generally requires a higher optimum temperature than does the reproductive phase (Hatfield and Prueger, 2015) [45]. Dormancy in temperate-zone fruits and nuts is naturally overcome by using extended periods of low winter temperature under high-moisture conditions (Van Nocker and Gardiner, 2014). There is a strong interaction effect between temperature and photoperiod on flowering in many species. The combination of an optimum temperature and a favorable photoperiod was used to accelerate flowering within critical limits (Adams et al., 1999). The environmental control of flowering by light and temperature has been practiced for many years (Hatfield and Prueger, 2015). For speed breeding, it is recommended that an optimal temperature regime (maximum and minimum temperatures) be applied for each crop (Ghosh et al., 2018). A higher temperature during the photoperiod and lower temperature during the dark period successfully accelerated the generation of wheat (Ghosh et al., 2018) [46].

Humidity

Relative humidity directly impacts the water availability of plants and indirectly affects leaf growth, photosynthesis, and pollination. Plant stomatal movements are based on vapor pressure deficit and air humidity. At high air humidity, a plant's water-usage efficiency decreases even when the stomata are open. At low humidity, transpiration is too high; therefore, plants close stomatal openings to reduce water loss, and wilting consequently slows photosynthesis, resulting in stunted plant growth (Georgii et al., 2017) [47]. Humidity is the most difficult environmental factor to control in controlled-environment chambers, but a reasonable range of 60-70% humidity is ideal (Ghosh et al., 2018). For crops that are more adaptable to drier conditions, a lower humidity level may be advisable (Ghosh et al., 2018) [48].

Abiotic stresses: where speed breeding can be implemented

Abiotic stresses are serious constraints on crop production and alone account for nearly 50% of yield losses in agricultural crops worldwide (Shinwari et al., 2020). Plants are frequently exposed to different abiotic stresses, such as drought, salinity, high and low temperatures, floods, heavy metal toxicity (e.g., Al31, Cl2, Cd21, Fe21, and Na1), and mineral deficiency (e.g., Fe31, N, P, S, and Zn21) (Mickelbart et al., 2015). Drought, salinity, cold, and heat lead to nearly 70% yield reductions in food crops across the globe. These abiotic stresses have a major impact on crop productivity and production (Roy et al., 2011). Approximately 40% of yield loss is caused by high-temperature stress, 20% of yield loss occurs due to salinity, and 17% and 15% of yield loss is caused by drought and low temperature, respectively (Ashraf et al., 2013) [49].

Other abiotic stresses, such as low temperature, excess water, heavy metals, mineral deficiency, and radiation, also lead to considerable yield penalties in crop production. Furthermore, global warming and climate change have increased the impact of abiotic stresses on crop yield. Limited success has been achieved in elucidating genetic and molecular mechanisms for abiotic stress tolerance, such as drought, salinity, cold, ion toxicity, and mineral deficiency (Roy et al., 2011). Understanding the tolerance mechanism to abiotic stress, from the perception of environmental signals to the cellular response, is very important for the development of crop improvement strategies for stress tolerance (Suprasanna et al., 2016). In the case of abiotic stress experiments, generation advancements, or phenotypic evaluations in abiotic stress studies, speed breeding can be integrated in a better way because it requires controlled glasshouse growth conditions.

A controlled environment can minimize experimental error and reduce the complexity of interactions between genetic and environmental effects on phenotype (G3E interaction) (Roy et al., 2011). A controlled environment allows monitoring of the start of some stresses, such as limiting water in drought stress, the addition of salts to hydroponics in salinity, and excessive watering. On the other hand, control conditions do not completely mimic the natural environment and cost-reducing reality, as plants are being grown in pot conditions rather than in the field. Under glasshouse conditions, preliminary abiotic stress experiments, such as water deficit stress (drought), excess water, temperature extremes, and salinity, are usually performed. Speed breeding can be a reliable tool and can be incorporated into regular breeding programs. Advanced breeding technologies focused on improving abiotic stress tolerance include transgenics, marker-assisted breeding, genomic selection, and express genome editing.

These methods can be used in various stages of the development of stress-tolerant cultivars. Speed breeding assists in defining target stress and environments, identifying superior parents, standardizing screens for stress tolerance, elucidating mechanisms of stress tolerance, identifying and characterizing genes conferring tolerance, pyramiding different tolerances in elite lines through marker-assisted breeding, evaluating breeding lines in target stress environments, etc. However, the use of speed breeding for abiotic stress tolerance is in its infancy.

Drought

Drought is considered one of the major constraints in sustainable crop production (Berger et al., 2010). The insufficient availability of sufficient water in the soil creates water deficit stress for plants. Drought stress has been found to limit productivity by reducing stem diameter, leaf area, plant height, and plant biomass in different crops (Zheng et al., 2016). The unpredictable heterogeneous nature of drought stress (variations between seasons and years and between regions) is of major concern. The constraints faced by breeders for developing drought-tolerant varieties can be easily removed by using speed breeding (Mitra, 2001). The speed-breeding platform helps to identify representative drought stress conditions, thereby providing homogenous conditions for screening. The evaluation of genotypes under controlled conditions can aid in the selection of promising individual plants. Reproducible and precise screening techniques can be used for the identification of superior genotypes for rapid breeding, thereby eliminating the selection of lines with a negative association between stress tolerance traits and yield. Multiple stresses affect plants; however, speed breeding helps to study each stress independently and elucidate the mechanism of stress tolerance. Speed breeding will help to expand research on abiotic stress in pulses and oilseed crops, as most of these efforts are confined to cereals.

Salinity

Salinity is another major abiotic stress and affects more than 20% of global agricultural irrigated land. Soil salinity is becoming an acute problem in agriculture because of the low water quality in arid and semiarid regions (Rhoades and Loveday, 1990). Salinity affects plant growth in many ways and in a slightly similar manner to drought by creating water deficit stress. Even though water is available in the soil in sufficient amounts, it cannot be taken up by plant roots due to differences in water potential, which are created under saline conditions. Salinity also causes nutrient deficiency in plants and thereby suppresses their growth, metabolism, and productivity. Efforts are being made to develop salt-tolerant cultivars through approaches such as conventional breeding, transgenics, and marker-assisted breeding. Although transgenic and marker-assisted breeding approaches have shortened the breeding process to a certain extent, there is still a need to improve the breeding process to meet the increasing food demand. Speed breeding can further hasten these processes. For example, salt-tolerant rice lines have been developed through combined marker-assisted breeding and speed breeding approaches (Rana et al., 2019). Speed breeding offers the potential to improve salinity tolerance and develop better cultivars of other crops, such as cereals, pulses, oilseeds, and vegetables, at a faster rate [50].

Temperature

Extreme temperatures (high/low) exerted a significant negative influence on crop productivity worldwide. High-temperature stress caused significant yield losses in different crops. High-temperature stress causes oxidative stress to crop plants and often occurs in conjunction with drought and other abiotic stresses. Like drought and salinity, low temperature or cold stress are also the most harmful abiotic stresses (Mboup et al., 2012). Cold stress can be divided into two types, namely, chilling stress (0C15C) and freezing stress (0C). Compared with temperate crops, agricultural and horticultural crops cultivated in tropical and subtropical regions are more prone to low-temperature stress (Ritonga and Chen 2020). Low temperature negatively affects many aspects of plant growth, namely, water transport, cell division, photosynthesis, survival, growth, and ultimately crop yield (Hasanuzzaman et al., 2013). Conventional breeding, transgenics, marker-assisted breeding, and genome editing approaches are being used by researchers worldwide for the improvement of temperature-stress tolerance in different crop species. The improvement of crops to these major abiotic stresses (drought salinity and temperature) can be fast-tracked with the integration of speed breeding [51].

Conclusion

The use of speed breeding can accelerate the development of high-performing cultivars with market-preferring traits by reducing the amount of time, space and resources invested in the selection and genetic advancement of superior crop varieties. This technique allows plant breeders to deliver improved crop varieties more rapidly. Streamlined operations that reduce labor and cost are key for the effective integration of speed breeding into crop improvement programmes. Furthermore, the integration of speed breeding with conventional, marker-assisted selection and genetic engineering breeding approaches can enhance the effective selection of elite genotypes and lines with novel traits, such as higher yield and better nutritional qualities, together with biotic and abiotic stress tolerance.

The most appropriate selection methods amenable to rapid breeding include single-seed descent, single-pod descent and single-plant selection methods. However, the adoption of speed breeding in many developing countries, especially in public plant breeding programs, is limited by the lack of trained plant breeders and plant breeding technicians and a lack of the requisite infrastructure and reliable supplies of water and electricity. Currently, there is also a lack of government support at the policy and financial levels to initiate and sustain rapid breeding in public plant breeding programs. The development of climate-resilient genotypes with high agronomic value through conventional breeding requires more time. The speed breeding strategy involves rapid generation advancements that result in faster release of superior varieties.

Through the development of disease-resistant varieties, the reduction of salt sensitivity in crops, and modifications to the duration, intensity, and temperature-controlled zone of light, speed breeding is a process that can be utilized to boost agricultural productivity. Through speed breeding, the photosynthetic process is enhanced, leading to accelerated crop development. This method makes it possible to release multiple generations of the same crop more quickly than with traditional breeding. By reducing the generation time, speed breeding is a novel method for quickly developing new long-day plant cultivars. A state-of-the-art method for developing plants in several generations annually is speed breeding. More generation times annually are needed to address food security issues. Generally, Speed breeding can accelerate the development of high-performing cultivars with desirable traits for the market by reducing the time, space, and resources needed for the selection and genetic advancement of superior crop varieties. Due to this technique, plant breeders can now provide improved crop varieties promptly. Streamlined operations that lower labor and lost-cost facilities are critical for integrating speed breeding into a crop development program.

References

1. Adams SR, Pearson S, Hadley P, Patefield WM (1999) The Effects of Temperature and Light Integral on the Phases of Photoperiod Sensitivity inPetunia× hybrida. Annals of Botany 83: 263-269.
2. Ahmar S, Gill RA, Jung KH, Faheem A, Qasim MU, et al. (2020) Conventional and molecular techniques from simple breeding to speed breeding in crop plants: recent advances and future outlook. International journal of molecular sciences 21: 2590.
3. Alahmad S, Dinglasan E, Leung KM, Riaz A, Derbal N, et al (2018) Speed breeding for multiple quantitative traits in durum. Wheat Plant methods 14: 1-15.
4. Alexandratos N, Bruinsma J (2012) World agriculture towards 2030/2050: the 2012 revision.
5. Ashraf M, Shahbaz M, Ali Q (2013) Drought-induced modulation in growth and mineral nutrients in canola (Brassica napus L.). Pak J Bot 45: 93-98.
6. Bantis F, Karamanoli K, Ainalidou A, Radoglou K, Constantinidou HIA, et al. (2018) Light emitting diodes (LEDs) affect morphological, physiological and phytochemical characteristics of pomegranate seedlings. Scientia horticulturae 234: 267-274.

7. Bayat L, Arab M, Aliniaeifard S, Seif M, Lastochkina O, et al. (2018) Effects of growth under different light spectra on the subsequent high light tolerance in rose plants. AoB Plants 10: ply052.

8. Begna T (2022) Speed breeding to accelerate crop improvement. Int J Agric Sc Food Technol 8: 178-186.

9. Berger B, Parent B, Tester M (2010) High-throughput shoot imaging to study drought responses. Journal of experimental botany 61: 3519-3528.

10. Bergstrand KJ, Schussler HK (2013) Growth, development and photosynthesis of some horticultural plants as affected by different supplementary lighting technologies. Eur J Hortic Sci 78: 119-125.

11. Breseghello F, Coelho ASG (2013) Traditional and modern plant breeding methods with examples in rice (Oryza sativa L.). Journal of agricultural and food chemistry 61: 8277-8286.

12. Budak H, Kantar M, Yucebilgili Kurtoglu K (2013) Drought tolerance in modern and wild wheat. The Scientific World Journal.

13. Bugbee B (2016) Toward an optimal spectral quality for plant growth and development: the importance of radiation capture. In VIII International Symposium on Light in Horticulture 1134 (pp. 1-12).

14. Chhetri M, Bariana H, Wong D, Sohail Y, Hayden M, et al. (2017) Development of robust molecular markers for marker-assisted selection of leaf rust resistance gene Lr23 in common and durum wheat breeding programs. Molecular Breeding 37: 1-8.

15. Crossa J, Beyene Y, Kassa S, Pérez P, Hickey JM, et al. (2013) Genomic prediction in maize breeding populations with genotyping-by-sequencing. G3: Genes genomes genetics 3: 1903-1926.

16. Curtis T, Halford NG (2014) Food security: the challenge of increasing wheat yield and the importance of not compromising food safety. Annals of applied biology 164: 354-372.

17. Davis PA, Burns C (2016) Photobiology in protected horticulture. Food and Energy Security 5: 223-238.

18. Georgii E, Jin M, Zhao J, Kanawati B, Schmitt-Kopplin P, et al. (2017) Relationships between drought, heat and air humidity responses revealed by transcriptome-metabolome co-analysis. BMC plant biology 17: 1-23.

19. Ghosh S, Watson A, Gonzalez-Navarro OE, Ramirez-Gonzalez RH, Yanes L, et al. (2018) Speed breeding in growth chambers and glasshouses for crop breeding and model plant research. Nature protocols 13: 2944-2963.

20. Hasanuzzaman M, Nahar K, Fujita M (2013) Extreme temperature responses, oxidative stress and antioxidant defense in plants. Abiotic stress-plant responses and applications in agriculture, 13: 169-205.

21. Hatfield JL, Prueger JH (2015) Temperature extremes: Effect on plant growth and development. Weather and climate extremes 10: 4-10.

22. Heffner EL, Sorrells ME, Jannink JL (2009) Genomic selection for crop improvement. Crop Science 49:1-12.

23. Hickey LT, Germán SE , Pereyra SA, Diaz JE, Ziems LA, et al. (2017) Speed breeding for multiple disease resistance in barley. Euphytica 213: 1-14.

24. Khoury CK, Bjorkman AD, Dempewolf H, Ramirez-Villegas J, Guarino L, et al. (2014) Increasing homogeneity in global food supplies and the implications for food security. Proceedings of the national Academy of Sciences 111: 4001-4006.

25. Li H, Rasheed A, Hickey LT, and He Z (2018) Fast-forwarding genetic gain. Trends in plant science 23: 184-186.

26. Liang C, Wang W, Wang J, Ma J, Li C, et al. (2017) Identification of differentially expressed genes in sunflower (Helianthus annuus) leaves and roots under drought stress by RNA sequencing. Botanical studies 58: 1-11.

27. Lin I, Sung J, Sanchez RJ, Mallya UG, Friedman M, et al. (2016) Patterns of statin use in a real-world population of patients at high cardiovascular risk. Journal of Managed Care & Specialty Pharmacy 22: 685-698.

28. Lopes MS, El-Basyoni I, Baenziger PS, Singh S, Royo C, et al. (2015) Exploiting genetic diversity from landraces in wheat breeding for adaptation to climate change. Journal of experimental botany 66: 3477-3486.

29. Mboup M, Bahri B, Leconte M, De Vallavieille-Pope C, Kaltz O, et al. (2012) Genetic structure and local adaptation of European wheat yellow rust populations: the role of temperature-specific adaptation. Evolutionary applications 5: 341-352.

30. Mickelbart MV, Hasegawa PM, Bailey-Serres J (2015) Genetic mechanisms of abiotic stress tolerance that translate to crop yield stability. Nature Reviews Genetics 16: 237-251.

31. Mitra J (2001) Genetics and genetic improvement of drought resistance in crop plants. Current science 758-763.

32. Mobini SH, Lulsdorf M, Warkentin TD, Vandenberg A (2015) Plant growth regulators improve in vitro flowering and rapid generation advancement in lentil and faba bean. In Vitro Cellular & Developmental Biology-Plant 51: 71-79.

33. Rana MM, Takamatsu T, Baslam M, Kaneko K, Itoh K, et al. (2019) Salt tolerance improvement in rice through efficient SNP marker-assisted selection coupled with speed-breeding. International journal of molecular sciences 20: 2585.

34. Ray DK, Mueller ND, West PC, Foley JA (2013) Yield trends are insufficient to double global crop production by 2050. PloS one 8: e66428.

35. Razzaq A, Sadia B, Raza A, Khalid Hameed M, Saleem F, et al. (2019) Metabolomics: A way forward for crop improvement. Metabolites 9: 303.

36. Rhoades JD, Loveday J (1990) Salinity in irrigated agriculture. Agronomy (30): 1089-1142.

37. Richard CA, Hickey LT, Fletcher S, Jennings R, Chenu K, et al. (2015) High-throughput phenotyping of seminal root traits in wheat. Plant Methods 11: 1-11.

38. Ristaino JB (2002) Tracking historic migrations of the Irish potato famine pathogen, Phytophthora infestans. Microbes and infection 4:1369-1377.

39. Ritonga FN, Chen S (2020) Physiological and molecular mechanism involved in cold stress tolerance in plants. Plants 9: 560.

40. Roy SJ, Tucker EJ, Tester M (2011) Genetic analysis of abiotic stress tolerance in crops. Current opinion in plant biology 14: 232-239.

41. Runkle ES, Heins RD (2001) Specific functions of red, far red, and blue light in flowering and stem extension of long-day plants. Journal of the American society for horticultural science 126: 275-282.

42. Samantara K, Bohra A, Mohapatra SR, Prihatini R, Asibe F, et al. (2022) Breeding more crops in less time: A perspective on speed breeding. Biology 11: 275.

43. Shiferaw B, Smale M, Braun HJ, Duveiller E, Reynolds M, et al. (2013) Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security. Food Security 5: 291-317.

44. Shimelis H, Laing M (2012) Timelines in conventional crop improvement: pre-breeding and breeding procedures. Australian Journal of Crop Science 6: 1542-1549.

45. Shinwari ZK, Jan SA, Nakashima K, Yamaguchi-Shinozaki K (2020) Genetic engineering approaches to understanding drought tolerance in plants. Plant Biotechnology Reports 14: 151-162.

46. Suprasanna P, Nikalje GC, Rai AN (2016) Osmolyte accumulation and implications in plant abiotic stress tolerance. In Osmolytes and plants acclimation to changing environment: Emerging omics technologies (pp. 1-12). New Delhi: Springer India.

47. van Nocker S, Gardiner SE (2014) Breeding better cultivars, faster: applications of new technologies for the rapid deployment of superior horticultural tree crops. Horticulture Research 1.

48. Varshney RK, Hoisington DA, Tyagi AK (2006) Advances in cereal genomics and applications in crop breeding. Trends in biotechnology 24:490-499.

49. Velez-Ramirez AI, Van Ieperen W, Vreugdenhil D, Van Poppel PM, Heuvelink E, et al. (2014) A single locus confers tolerance to continuous light and allows substantial yield increase in tomato. Nature communications 5: 4549.

50. Von Braun J (2005) The world food situation: An overview. Washington, DC: International Food Policy Research Institute.

51. Watson A, Ghosh S, Williams MJ, Cuddy WS, Simmonds J, et al. (2018) Speed breeding is a powerful tool to accelerate crop research and breeding. Nature plants 4: 23-29.