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Speed Breeding: One of the Rapid Generation Advancement Approaches

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Speed breeding is a cutting-edge breeding method with the potential to revolutionize the agricultural industry. Speed breeding significantly reduces the time it takes for crops to mature, enabling the production of several generations each year. This is accomplished by adjusting environmental conditions like temperature, light quality, and photoperiod duration. Researchers and breeders can create new crop varieties with desired features more quickly thanks to this faster breeding procedure. Compared to conventional breeding techniques, speed breeding has a number of benefits. It makes it simpler to generate improved cultivars with higher yield, disease resistance, and other desirable qualities since it enables the swift evaluation and selection of plant

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attributes. Speed breeding speeds up the breeding process, allowing scientists to adapt to shifting environmental factors and developing agricultural problems more quickly. While speed breeding offers tremendous potential, there are also limitations and challenges associated with its implementation. Factors such as plant species, specific traits, and optimal growth conditions need to be carefully considered. This system involves manipulation of growing conditions by different ways, here three of the methods are described. As the population of world is increasing day by day so to overcome the risk of global food security and to cope with such future problems, such rapid crop improvement approaches need to be implemented. Speed breeding approach is an old concept but its implementation in the field of breeding has not been exploited to a greater extent. However, ongoing advancements in technology and further research is likely to overcome these challenges, making speed breeding an increasingly valuable tool for crop improvement in the future.

Keywords: Conventional; crop improvement; photoperiod; quick; speed breeding; temperature.

1. INTRODUCTION

In the next three decades, it is projected that the global human population will increase by 25%, reaching a total of 10 billion individuals [1-3]. While traditional breeding methods have successfully generated nourishing crops with high yields that can be mechanically harvested to address the food requirements of the expanding population, the current rate of yield improvement for major crops like wheat, rice, and maize will be inadequate to meet future demands. There is mounting pressure on breeders and plant scientists to enhance existing crops and create new varieties that are not only higher yielding and more nutritious, but also resistant to pests, diseases, and adaptable to changing climates. The rapid changes in climate and the emergence of novel pests and diseases pose significant threats to agricultural production. Consequently, the urgent concern today is to produce a greater quantity of high-quality food to satisfy the ever-growing population. Additionally, there is a need to surpass the current levels of genetic progress achieved through conventional breeding programs, necessitating the adoption of new and innovative approaches [4,5]. One such tool or technique is speed breeding, which expedites crop research and boosts food production by significantly reducing the time it takes for crops to mature and be harvested. The rapid generation advancement principle in crop breeding plays key role in future [6]. With the rapidly increasing population, there is increased food demand and to cope up with the needs, it important to focus on increasing the overall crop yield by various means [7-9]. The goal of this article is to propose speed breeding as one of the rapid advancement methods in the field of crop production.

2. SPEED BREEDING (SB)

'Speed breeding' is breeding which greatly shortens generation time of crops by adjusting the photoperiod length and controlled temperature condition which accelerates breeding and thus producing more number of generations of crops per year.

This method was initially developed by NASA partnered with Utah State University to explore the possibility of growing rapid cycling wheat under constant light on space stations and they were successful in developing dwarf wheat line. After NASAs experiment, the team at the John Innes Centre, University of Queensland and University of Sydeny utilized this method for wheat crop production. Then the term "Speed Breeding (SB)" was given by University of Queensland. Speed breeding is also a form of Rapid Generation Advancement (RGA).

The method was initially explained and executed on wheat and peanuts. This technique utilizes specific light quality, intensity, day length, and temperature control to expedite the process of photosynthesis and flowering. Additionally, it involves early seed harvesting to shorten the time required for each generation. By employing speed breeding, it is possible to achieve up to six generations of spring wheat, durum wheat, barley, chickpea, and pea, as well as four generations of canola instead of the typical 2-3 generations in a regular greenhouse setting. The use of supplementary lighting in a greenhouse environment enables rapid cycling of generations through a technique called single seed descent (SSD), which has the potential to be applied to larger-scale crop improvement programs. SSD is commonly used in breeding and research initiatives to aid in the development of homozygous lines after a crossbreeding with desired traits. One of the reasons for utilizing SSD is to address the increasing population growth each year and to reduce seed losses.

Furthermore, the use of light-emitting diode (LED) supplemental lighting is highlighted as a cost-saving measure in this breeding process. The speed breeding experiments, referred to as I, II and III, utilize artificial light sources with enhanced photosynthetically active radiation (PAR) in the blue, red, and far-red regions of the spectrum. LED lights are now manufactured with programmable features that optimize PAR, allowing customization of wavelength and intensity to suit different growth stages of plant species. In the case of most crop plants, the breeding of new and improved cultivars usually requires several years, which is particularly time-consuming for field-grown crops that typically go through only 1-2 generations per year. However, speed breeding, which involves extended photoperiods to accelerate plant development and harvest and germination of immature seeds, has the potential to reduce generation time. To investigate the effectiveness of speed breeding in accelerating SSD, where plants are typically grown at high density, it was observed that plants grown at higher density had shorter generation times. This could be attributed to stress or plant competition resulting from the increased density, which is known to expedite flowering. It is unlikely that the direct application of speed breeding protocols to short-day species such as maize or rice would yield successful results, as there is likelihood of room for optimization to achieve faster generation times in these particular species. The growing global population and the impact of a changing environment have raised significant concerns regarding food security. Traditional breeding methods may not be able to meet future food demands. Therefore, the development of speed breeding as a breeding method aims to address this challenge. Speed breeding has the potential to significantly enhance plant growth performance in both academic and commercial research sectors, spanning a wide range of species.

3. METHODS OF SPEED BREEDING

Speed Breeding I: Controlled-environment chamber speed breeding.

Speed Breeding II: Glass house speed breeding conditions.

Speed Breeding III: Homemade growth room design for low-cost speed breeding.

1) **Speed Breeding I:** Controlled-environment chamber speed breeding.

- ✓ In this the Conviron BDW chamber is used.
- ✓ Photoperiod of 22 hours with 22ºC temperature and 2 hour dark periods with
- ✓ 17ºC temperature is provided which helps to improve plant health.
- ✓ Humidity in such system is maintained at 70%.
- ✓ In this system/method, temperature is set to ramp up and down for 1 hour 30 minutes to mimic natural dawn and dusk condition.
- ✓ The lighting is supplied by mixtures of white LED bars, far -red LED lamps and ceramic metal hydrargyrum quartz iodide lamps.
- ✓ Light Intensity of 360–380 µmol/m^2/s at bench height and 490 – 500 µmol µmol/m^2/s at adult plant height is provided.
- ✓ This system has been used for crops like wheat, barley and *brachypodium.*

2) **Speed Breeding II:** Glass house speed breeding conditions.

- ✓ In this method, temperature controlled glass house fitted with high pressure sodium vapor lamps is used.
- ✓ The temperature is maintained at 17/22 ºC with 12 hour turnover.
- ✓ The photoperiod of 22 hour light and 2 hour dark period is provided (helpful to Improve plant health) without lamps at 17 ºC temperature.
- ✓ In this method there is no any light and temperature ramping up or down procedure.
- ✓ Light Intensity of 440-650(Adult Plant height) µmol/m^2/s (approximately 45cm above bench height) is provided.
- ✓ This system has been used for crops wheat, barley, chickpea, and canola.

3) **Speed Breeding III:** Homemade growth room design for low-cost speed breeding.

- ✓ In this system room of 3m×3m×3m with insulated sandwich panelling is fitted
- ✓ with seven LB-8 LED light boxes.
- ✓ A 1.5horsepower inverter split system domestic air conditioner is set up as a
- ✓ low-cost alternative to the Conviron BDW chamber.
- ✓ Automatic watering is achieved with the Irrigation Controller.
- ✓ The humidity conditions are ambient.

- ✓The lighting is set to run a 12-hour photoperiod (12hours of darkness) for 4 weeks and is then increased to an 18-hour photoperiod (6hours of darkness).
- ✓The lights do not ramp up and down during the switch between light and dark periods in the 24-hour cycle.
- ✓The air-conditioner is set to run at 18°C in darkness and 21°C when the LED lights are on, with fluctuation being no more than ±1°C.
- ✓Light Intensity of 210–260 (bench height) & 340–590 (adult plant height) µmol/m^2/s is provided.
- ✓This system has been used for the crops wheat, barley, oat and triticale.

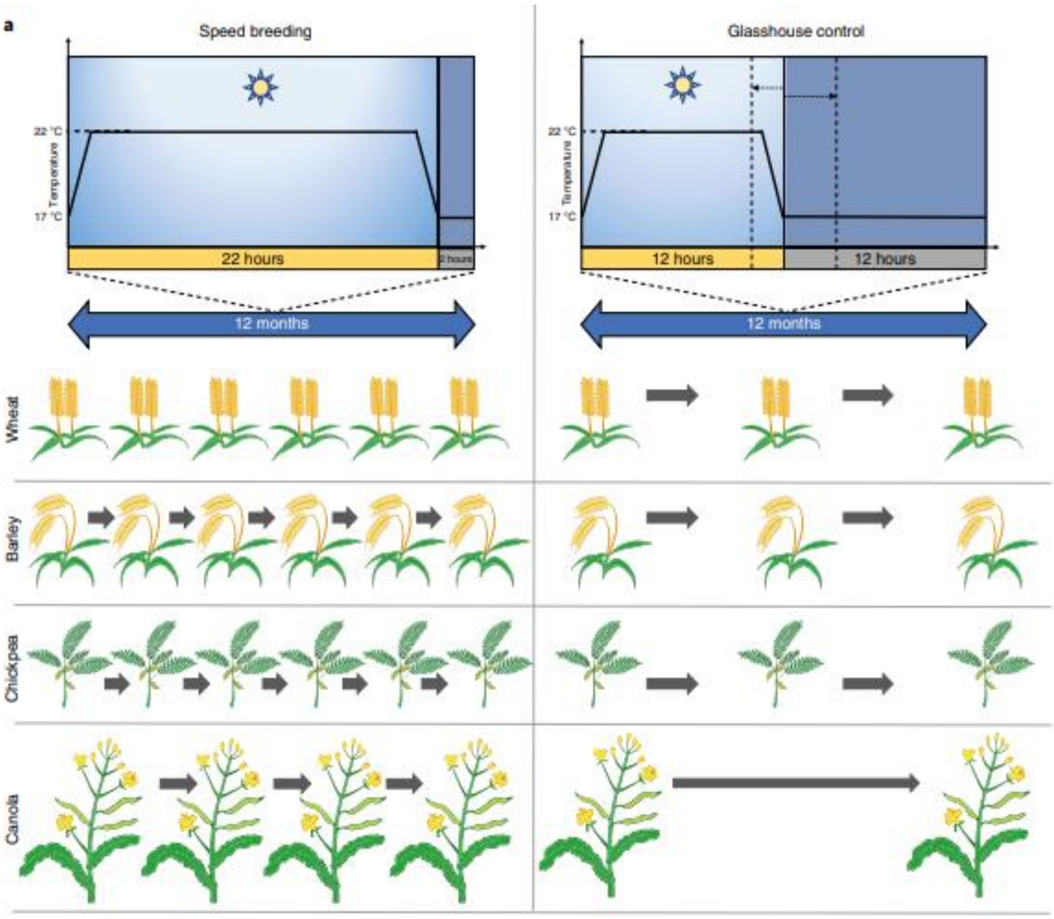

Fig. 1. Speed breeding accelerating plant generation as compare to normal glasshouse condition

Source: Watson et al. [10]

4. APPLICATIONS OF SPEED BREEDING

1. The document also provides information on the cost-saving benefits of implementing light-emitting diode (LED) supplemental lighting.
2. It can be applied to various significant crop species, such as wheat, barley, and chickpea, enabling the production of 4 to 6 generations per year depending on the variety, without compromising subsequent generations' yield.
3. By combining speed breeding and SSD techniques, it is possible to expedite the generation of inbred lines for research and plant breeding programs effectively.
4. Speed breeding offers the opportunity to accelerate the generation time and phenotype key adult plants, such as wheat and barley.
5. It can be utilized for evaluating diseases by introducing resistant and susceptible plants, like infecting wheat spikes with *Fusarium graminearum*, which causes fusarium head blight (FHB).

6. Speed breeding proves useful in assessing the loss of function of a specific locus across different generations, as demonstrated in the F6 recombinant inbred line of Paragon x W352 under speed breeding conditions, focusing on the FLOWERING LOCUS T-B1.
7. The study also examines the pairing of polyploid wheat chromosomes at metaphase I during meiosis, both with and without the PAIRING HOMOEOLOGOUS 1 (Ph1) locus.
8. Adult plant phenotypes can be accurately recapitulated much faster compared to the corresponding conditions in a greenhouse.
9. Different growth parameters, such as photoperiod, temperatures, plant density, and watering regime, can be adjusted to accelerate the generation time.
10. Speed breeding allows for the rapid generation of fixed populations through SSD, which may be a cost-effective alternative to generating double haploids, facilitating subsequent field evaluation and selection and enhancing genetic gain and cultivar production.
11. In the case of genetically well-defined traits, speed breeding can be employed to swiftly introgress genes or haplotypes into elite lines using marker-assisted selection.
12. In the context of breeding, the ability to rapidly advance generations to homozygosity after crossing enhances genetic gain for essential traits.
13. Speed breeding enables breeding programs to produce improved cultivars more rapidly.
14. It is valuable for comparing the physiological, morphological, and yield parameters of crops.
15. Speed breeding requires less land, labor, and machinery as compared to field breeding.
16. The speed breeding system is less vulnerable to adverse biotic and abiotic stresses, such as reduced rainfall, low diurnal temperatures, and foliar diseases. Moreover, it provides breeders with greater flexibility in generating new breeding materials.
17. Speed breeding can expedite the discovery and utilization of allelic diversity in landraces and wild relatives of crops. For instance, screening the Vavilov wheat collection for leaf rust resistance using speed breeding, combined with DNA markers linked to known genes, led to the identification of new sources of resistance.
18. It can be seamlessly integrated with genomic selection, genome editing, and other techniques.

5. LIMITATION OF SPEED BREEDING

1. Plant species exhibit distinct responses when subjected to prolonged periods of light exposure.
2. Extended photoperiods often accelerate the time to flowering in long day plants by surpassing the critical day length. Day-neutral plants also exhibit this phenomenon, as they flower irrespective of the photoperiod.
3. Short-day (SD) plants require a photoperiod shorter than the critical day length for flowering, which may conflict with extended light conditions.
4. When the response to photoperiod is unclear or intricate, it becomes necessary to experiment with light and temperature variables to optimize a strategy for extended light conditions.
5. While this approach works well for certain activities like crossing, single seed descent (SSD), and screening for simple traits, other tasks such as selecting for adaptation to the target environment still need to be carried out in the field.
6. Expediting the generation time through early harvest of immature seeds can hinder the phenotyping of certain seed traits.
7. If suitable facilities are not already available, establishing a greenhouse or acquiring a growth chamber with appropriate supplementary lighting and temperature control capabilities entails a significant initial investment.
8. The cost-benefit analysis depends on the budget of the research or breeding program.
9. The outcomes are heavily reliant on the crop species and can vary significantly among different cultivars.
10. The quality of light, duration of the photoperiod, and temperature conditions also influence the extent to which the generation time is reduced.
11. It's important to note that the strength and duration of ambient sunlight vary with location and season, leading to variations in the rate of plant development.
12. Manipulating basic growth conditions like soil type can be employed to achieve optimal parameters for the specific crop of interest.

6. ACHIEVEMENTS OF SPEED BREEDING

1. USU-Apogee - a dwarf wheat line – NASA and Utah State University.

2. DS Faraday – High protein and milling wheat variety.

3. YNU31-2-4 – Salt Tolerance rice variety.

4. By speed breeding program, growing up to six generation per year is possible in wheat, barley, chickpea and up to four generations of canola.

7. OTHER METHOD TO REDUCE GENERATION TIME

1. Use of embryo rescue
2. Growth regulator
3. Increasing physiological stress
4. Increasing CO_2 concentration.
5. Double haploid (DH) techniques, etc

8. CONCLUSION

The breeding program needs to align with the changing climate, and the immediate challenge is to breed resilient crops that can withstand these changes. This challenge can be addressed through innovative approaches like speed breeding. Speed breeding is an effective tool that can help achieve the genetic gain targets for food, feed, fiber, and fuel by 2050. By combining speed breeding with technologies such as marker-assisted selection, genomic selection, and CRISPR gene editing, the desired outcomes can be achieved much faster. In countries with limited resources like ours, speed breeding is a viable option to shorten the breeding cycle and accelerate the research program. The field of agricultural science has extensively explored various research avenues and has leveraged plant biology and ecology to enhance traits. Speed breeding involves developing crop-specific protocols by manipulating the photoperiod, optimizing controlled environmental conditions like temperature, humidity, and light, and implementing stage-specific assessments to achieve more than five generations per year without compromising yield. This approach not only emphasizes greenhouse control measures but also prioritizes the specific needs of the plants when establishing the protocols. The article primarily focuses on wheat crops and discusses key aspects and limitations of speed breeding, including the high initial cost and the variation in protocols depending on the crops involved.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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