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Speed Breeding: A Potential Tool to Facilitate Vegetable Improvement Programme

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Speed breeding (SB) is a new agricultural technology that seeks to reduce the breeding period and speed up the crop improvement process by means of quick generation advancement. Speed breeding allows breeders of plants to breed multiple generations per year by lengthening the photoperiod and controlling the growing environment through manipulating the temperature, light intensity, humidity, and CO2 concentration, and radically shortens the time it takes to breed out varieties. As the world population continues to rise at an alarming pace with an estimated population of 9.7 billion by 2050, the world will require an increase in food production of about 50 percent by the year 2020. Speed breeding is an effective solution to this as it can reduce line development timelines, which normally take 5-10 years, to as short as 2 years. This article summarizes the history, philosophy, practices and successes of speed breeding in vegetable crops, its current involvement in the state of the art of plant breeding methodologies, and its future potential to provide food security solutions to the food challenges of the future

Keywords: Speed breeding, photoperiod, generation advancement, vegetable improvement, rapid breeding cycle

Introduction

World population is on a terrifying rise, with the number of people estimated to reach about 9 billion by 2050, which would require a 50% rise in the food output level during the upcoming 20 years (UNDESA 2019; FAO, 2017). Adding to this difficulty are threats of climate change that can decrease the possible yield of crops up to 20 percent, greater pest, disease, and weather extremes (Zhao et al., 2017). Traditional methods of breeding plants to develop varieties are time-consuming and in most cases, are unsuitable to satisfy market demands. The low rate of improvement in some of the crop species can be greatly connected to the long generation time of such plants.

Speed breeding is a new technology in this regard. According to Begna (2022), defined as a method characterized by the prolongation of photoperiod and control of growing conditions, speed breeding allows advancing the generation development through a reduced breeding cycle. It tackles a serious bottleneck in breeding the time interval between initial cross to commercial release, a breed which generally requires 9-18 years comprising of line development, field testing and release stages. Speed breeding focuses on the line development phase and shortens it to the range of 2-5 years (with no change in the field testing or release schedules).

History of Speed Breeding

Speed breeding dates back to the 1990s, when NASA, in conjunction with Utah State University, explored the potential of cultivating rapid-cycling wheat in space stations. This research led to the development of a dwarf wheat genotype, USU-Apogee, which was grown under continuous artificial light to accelerate its life cycle, and it flowers in 25 days after sowing. (Bugbee & Salisbury, 1988; Monje *et al.*, 2003). These early findings encouraged plant scientists at the University of Queensland, University of Sydney, and the John Innes Centre to explore similar approaches for crop improvement under controlled conditions. DS Faraday is the first variety which developed through Speed Breeding

The term "speed breeding" was formally introduced by Lee T. Hickey and colleagues in 2003 at the University of Queensland, who demonstrated its effectiveness in crops such as wheat and peanuts. The scientific foundation of speed breeding as a plant breeding technology was established in their landmark study published in Nature Plants in 2018, which showed that up to six generations per year could be achieved in crops like wheat, barley, chickpea, pea, and canola under extended photoperiod and controlled environmental conditions (Watson et al., 2018).

Methods and Components of Speed Breeding

There are three main ways of carrying out speed breeding with differences in required infrastructure and cost.

Controlled Environment Chamber: This technique employs dedicated growth chambers with long photoperiods (usually 22 h light/2 h dark) and the temperature held at about 22 °C during the light period and 17 °C during the dark period, with a relative humidity of about 60-70. The intensity of the light (photosynthetic photon flux density, PPFD) is controlled based on the crop development stage-such as 350-400 µmol m-1 s-1 in wheat in the vegetative stage and up to around 500 µmol m-1 s-1 in the later stages (Watson et al., 2018; Ghosh et al., 2018)

Glasshouse Speed Breeding: In this method, they use temperature-controlled glasshouses to cultivate plants with the aid of high-pressure sodium vapour lamps or LEDs, extending the photoperiod to 22 hours. Light intensities are usually 400-650 µmol m -s -1, which supports rapid plant growth compared to controlled chambers (Watson et al., 2018).

Homebuilt Growth Room: An efficient alternative in terms of cost is insulated rooms, which will have LED lighting and regular air-conditioning apparatus. After early stages of growth, photoperiods can be established at 12 h and increased to 16-18 h. By so doing, resource-limited institutions can implement speed breeding with lowered costs of infrastructure (Watson et al., 2018; Hickey et al., 2019).

The most important variables to control speed breeding are manipulation of photoperiod, temperature, light quality (e.g., LEDs, sodium vapour lamps), light intensity (PPFD), humidity (60-70%), CO 2 (>400 ppm), nutrients, and the application of such techniques as immature seed harvesting and tissue culture. All of these aspects lead to fast germination, vegetative growth, early flowering, and swift seed development, significantly reducing the length of the crop life cycle and allowing multiple crops to be grown within a year (Watson et al., 2018; Hickey et al., 2019).

Strategies to Achieve Speed Breeding

There are a number of biological and environmental approaches to rapid generation improvement in crop plants:

Adjusted photoperiod and temperature: Speed breeding involves manipulation of photoperiod and temperature. Long-day and day-neutral crops flower earlier when exposed to longer photoperiods (e.g., 20-22 h), and short-day plants flower in response to lower photoperiods and optimal temperature programs (22/17 °C Day/night) (Hickey et al., 2018; Watson et al., 2018).

Exerting physiological stress: Moving to reproductive stages can be accelerated by applying mild stress conditions, including the limited root volume, limited irrigation, and controlled nutrient supply, to induce early flowering and seed set (Hickey et al., 2019).

Embryo rescue: Growth of immature embryos in vitro on nutrient media, in the presence or absence of plant growth regulators allows rapid germination and avoidance of seed dormancy. This is a technique that is especially very useful in reducing the generation cycles and restoring hybrids (Collard & Mackill, 2008).

High CO_2: High CO 2 (>400 ppm) levels can boost photosynthetic efficiency in C3 plants, which results in greater biomass production and may lead to earlier flowering and seed production (Ainsworth and Long, 2005).

Double haploids (DH): Doubled haploid technology has made it possible to produce fully homozygous lines in a single or two generations, as opposed to six or more generations that would be taken during traditional selfing and breeding programs are therefore sped up significantly (Forster et al., 2005).

Flowering gene manipulation: By manipulating key flowering regulators genetically (e.g., the photoperiod and vernalization genes FT, CO, VRN, etc.), crop species can be induced to flower early and have a shorter generation time (Andrés and Coupland, 2012).

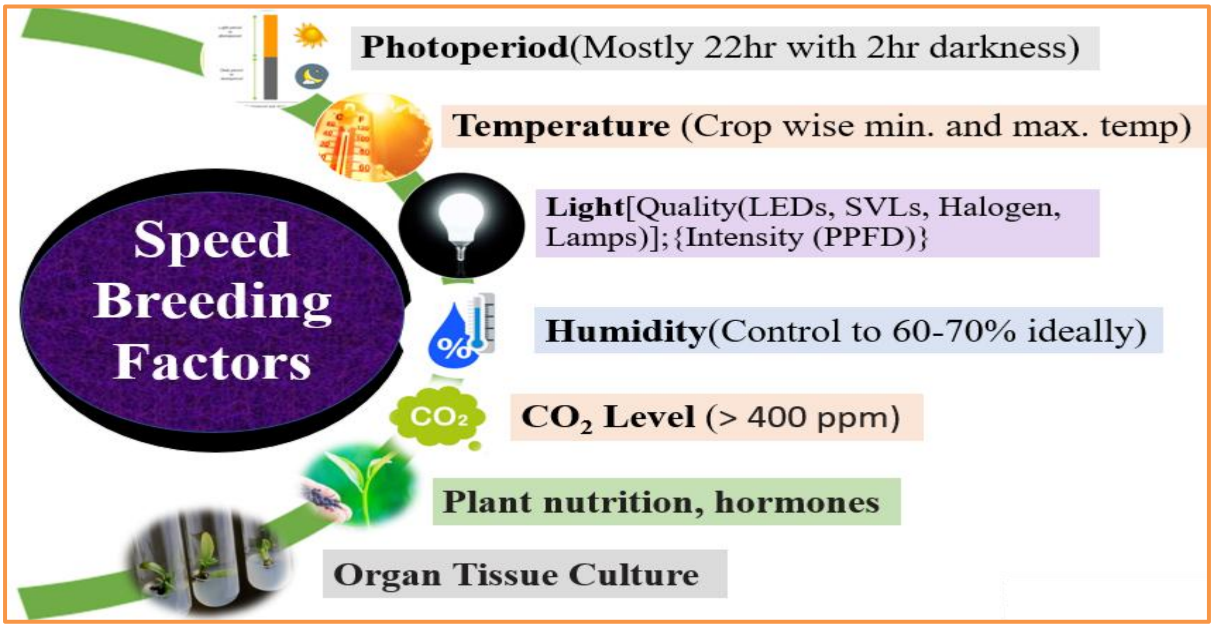

Fig 1: Components of speed breeding (Adapted from Benga,2022)

Achievements in Vegetable Crops Through Speed Breeding

Speed breeding has shown to be widely applicable to a wide variety of vegetable crops in controlled environmental conditions. Tomato (*Solanum lycopersicum*), pepper/chilli (*Capsicum annuum*), and other solanaceous crops can exhibit nearly the same speed of reaching 3-4 generations per year with flowering periods of 60-70 days and 40-70 days respectively (Velez-Ramirez et al., 2014; Liu et al., 2022 Eggplant (*Solanum melongena*) is another good responder, with 3-4 generations per year being possible in prolonged regimes of photoperiod. Onion (*Allium cepa*) is a biennial crop species that can be subjected to 2-3 generations annually with dormancy breaking, photoperiod control, and temperature regulation (in bulb and tuber crops) and potato (*Solanum tuberosum*) can also have similar turnover (2-3 generations per year) with long-day flowering (70-90 days) (Khosa et al., 2018). Cucumber (*Cucumis sativus*) is one of the cucurbits capable of flowering within 30-40 days and producing 3-4 generations annually in the favorable conditions of light and temperature (Ghosh et al., 2018). Leafy vegetables such as lettuce (*Lactuca sativa*) and spinach (*Spinacia oleracea*) possess short life cycles and exhibit strong photoperiod-induced bolting responses, enabling rapid generation turnover under controlled environments (Chun et al., 2001; Ghosh et al., 2018). Root crops such as radish (*Raphanus sativus*) can complete multiple generations per year due to their inherently short growth duration and rapid reproductive transition (Kitashiba et al., 2014). In contrast, carrot (*Daucus carota*), being a biennial crop, requires vernalization for flowering, and its generation advancement can be accelerated under controlled environmental conditions (Ghosh et al., 2018; Watson et al., 2018). Leguminous vegetables pea (*Pisum sativum*), French bean (*Phaseolus vulgaris*), and cowpea (*Vigna unguiculata*) have the potential to generate 3-5 generations per year via integration of photoperiod extension, plant growth regulators, and immature seed germination practices (Mobini and Warkentin, 2016). Moreover, related crops like Brassica oleracea, Brassica napus, and Brassica rapa have been promoted successfully under long photoperiod (22 h light), whereas amaranth (*Amaranthus spp*.) is highly responsive, with up to six generations annually and flowering in as little as 28 days after sowing (Stetter et al., 2016). In general, these illustrations show that manipulating photoperiod, temperature and controlled environments through speed breeding is an extremely efficient method of increasing the generation turnover in a broad range of vegetable crops.

Fig 2: Speed breeding under LED lights showing rapid plant growth.

Integration with Modern Plant Breeding Technologies

Speed breeding realizes its maximum effect in combination with complementary technologies. The combination of its work with the CRISPR-Cas9 gene editing makes it possible to multiply genetically edited lines quickly, and breeders can easily test and exclude lines with the desired phenotype, e.g. pest resistance or enhanced nutritional quality (Zsögön et al., 2018). Speed breeding can be used together with genomic selection to decrease length of the breeding cycle and time to genetic gain and develop superior varieties in much shorter periods. Speed breeding is complemented by high-throughput phenotyping systems, such as drone-based imaging and automated sensors, which provide the ability to get massive amounts of data as fast-evolving generations progress. The further acceleration of gene introgression is achieved through Marker-assisted selection (MAS) which enables the targeted selection at the molecular level to be made in addition to evaluation based on field performance alone.

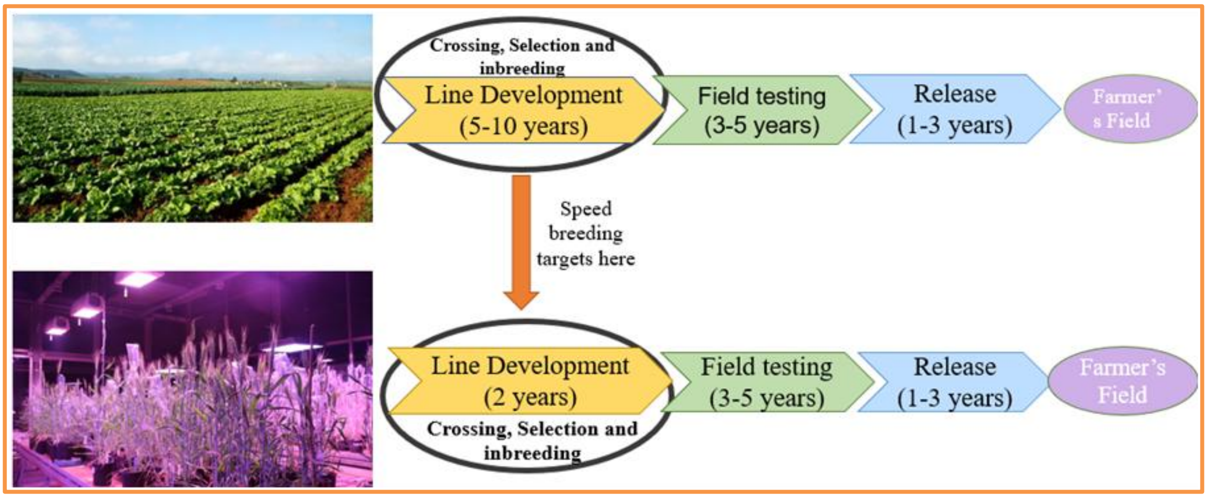

Fig 3. Timelines of varietal development with (a) Conventional breeding and (b) Speed breeding (Samantara et al., 2022)

Applications and Limitations

The extensive applications of speed breeding in contemporary plant breeding include: breeding 4-6 generations/year in crops such as pea; rapid generation of homozygous lines through Single Seed Descent (SSD); generation of double haploid (DH) lines; generation of genetically diverse mapping populations to study QTL and association with an individual gene; mutation breeding; and gene introgression using marker-assisted but speed breeding is not devoid of limitations. Plants that have short-day photoperiods, and which flower only after a critical photoperiod, might not be as well adapted to long light conditions as long-day or day-neutral crops. The reduced generation time might curtail phenotyping of some seed characteristics, including grain dormancy. Problems like chlorosis as a result of prolonged exposure to light may emerge, which needs to be handled carefully. Initial expenses of controlled environment chambers are expensive and technical expert manpower is needed to achieve success.

Future Prospects and Conclusion

Speed breeding is an effective and multi-purpose instrument that can be used to hasten crop improvement in a time of desperate food security demands. Its ability to work with single seed descent (SSD), single pod descent (SPD), and single plant selection (SPS) techniques minimizes reliance on traditional methods of selection, which are often time-consuming. Additionally, speed breeding has great potential to rapidly advance the development of transgenics and to allow the investigation of how plants respond to environmental stressors in a controlled and rapidly cyclable manner. With the increased availability of technology with innovations like the GrowCab flat-packed growth chamber and speed breeding capsules made out of recycled shipping containers, it is likely to be widely adopted by resource-limited and orphan crop breeding programs across the globe. In conclusion, speed breeding is a new and dynamic approach for developing improved crop varieties faster. It can fulfill the needs of the future food industry, help to mitigate climate change, and decrease the time it takes to move better vegetable and crop strains out of the laboratory and into the farmers field when combined with the use of genomic tools, gene editing, and precision phenotyping.

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