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SPEED BREEDING IN VEGETABLES: ACCELERATING GENETIC GAINS FOR THE FUTURE

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Vegetable crops are an important component of human nutrition and food security as they provide essential vitamins, minerals, fiber, and antioxidants. The demand for vegetables is increasing rapidly due to population growth, urbanization, and rising awareness about healthy diets. To meet this demand, the development of improved vegetable varieties with high yield, better quality, and resistance to pests, diseases, and abiotic stresses is essential.

Conventional plant breeding methods have successfully contributed to crop improvement; however, these methods are often time-consuming. The development of a new variety through traditional breeding may require 6–12 years or more**,** depending on the crop and breeding objectives. With the increasing challenges posed by climate change, emerging pests and diseases, and the need for sustainable agricultural production, faster breeding approaches have become necessary.

Speed breeding is an innovative technique that accelerates plant growth and shortens the breeding cycle by manipulating environmental conditions such as photoperiod, temperature, and light intensity. This approach enables breeders to grow multiple generations of crops within a single year, thereby significantly reducing the time required for variety development (He *at al.* 2024). Speed breeding is gaining importance in modern crop improvement programs and is being applied to several crops, including vegetable crops.

Principles of Speed Breeding

The goal of speed breeding is to accelerate plant development from germination to seed set (Blinkov *et al.* 2025). Key principles includes:

1. **Extended Photoperiod** – Providing 20–24 hours of light/day to promote early flowering and rapid growth.
2. **Temperature Optimization** – Adjusting day/night temperatures to maximize vegetative growth without causing stress.
3. **Early Seed Harvesting** – Collecting seeds before full maturity for the next generation.
4. **Controlled Environment Facilities** – Using growth chambers, greenhouses, or vertical farms to maintain ideal growth conditions year-round.

Application of Speed Breeding in Vegetable Crops

Tomato (*Solanum lycopersicum*)

Tomato is one of the most extensively studied vegetable crops in speed breeding programs due to its relatively short life cycle and high adaptability to controlled environmental conditions. The use of extended photoperiods and optimized temperature regimes significantly accelerates flowering and fruit development.

Hu *et al.*, (2025) Speed breeding of tomato was evaluated in a plant factory using cultivars Zuanhongmeili and Xiaokeai. Under a 12 h photoperiod, light intensities of 300–400 $\mu mol \cdot m^{-2} \cdot s^{-1}$ accelerated development, enabling flower bud emergence at ~25 DAS and germinable seed harvest at 60–63 DAS. Using 350 $\mu mol \cdot m^{-2} \cdot s^{-1}$, photoperiod optimization showed that a 20 h photoperiod further promoted growth and reproductive development. Under these conditions, seeds were harvested at 72–76 DAS. Overall, optimized light regimes can enable up to six tomato generations per year in controlled environments, supporting rapid breeding

Speed breeding in tomato has been widely used for the rapid development of disease-resistant varieties, particularly against pathogens such as bacterial wilt and late blight. Additionally, it facilitates the improvement of fruit quality traits, including firmness, soluble solids content, and shelf life. The approach is also useful in developing heat-tolerant and climate-resilient tomato cultivars.

Capsicum (*Capsicum annuum*)

Capsicum, including both sweet pepper and chilli pepper, generally exhibits a longer reproductive phase compared to other vegetable crops. However, speed breeding techniques can significantly reduce the time required for generation advancement.

In a study by Liu *et al.*, (2022)**,** two hot pepper varieties (Xiangyan 55 and Xiangla 712) grown under controlled light conditions flowered at about 39.9 days after sowing under PPFD 420 µmol m^{-2} s^{-1} with a 12-h photoperiod, producing viable seeds by 82 days; supplementation with far-red light (R:FR = 2.1) accelerated fruit ripening and improved seed germination, enabling up to four generations per year. Similarly, Choi *et al.*, (2023) demonstrated that a 20-h photoperiod combined with far-red light reduced the time to first harvest to about 95 days compared with 170 days in control conditions and enabled a seed-to-seed cycle of ~110 days, while genetic analysis identified flowering-related genes such as AP2, WOX4, FT, and GI**,** highlighting the effectiveness of speed breeding in accelerating pepper breeding and genetic improvement.

The technology has proven particularly useful for the rapid development of virus-resistant cultivars, including resistance to tomato leaf curl virus and other economically important pathogens. Speed breeding also facilitates the development of high-yielding hybrid parental lines and the improvement of fruit quality and capsaicin content in chilli peppers**.**

Lettuce (*Lactuca sativa*)

Lettuce is well suited for speed breeding because of its short life cycle and rapid transition from vegetative growth to reproductive development under extended photoperiod conditions**.** The crop shows strong responsiveness to controlled environmental manipulation.

Optimal conditions for lettuce speed breeding include a photoperiod of 20–22 hours and temperatures maintained between 20–24°C**.** Under conventional breeding systems, lettuce generally requires 3–4 months to complete a generation**.** Speed breeding can reduce this duration to approximately 30–40 days, allowing five to six generations per year. Zhang *et al.*, (2024) reported that Plant Factory Technology (PFT) provides a controlled agricultural environment where factors such as light regimes, temperature, CO_2 concentration, and nutrient supply can be precisely managed. Using lettuce as a model crop, their study demonstrated that PFT can accelerate breeding processes and improve vegetable nutritional quality within a shorter production period compared with conventional open-field cultivation.

This rapid cycling greatly enhances breeding efficiency for traits such **as** bolting resistance, leaf morphology, color development, and nutritional quality. Additionally, speed breeding is useful for developing functional lettuce varieties with enhanced levels of vitamins and antioxidants**.**

Spinach (*Spinacia oleracea*)

Spinach is another leafy vegetable crop that responds well to extended photoperiod conditions. The crop is particularly sensitive to day length, which can be exploited to accelerate flowering and seed production.

Ibrahim *et al.,* (2025) reported that LED-based speed breeding with extended photoperiods (13–19 h) significantly enhanced spinach vegetative growth, with a 19-h photoperiod producing the highest stem length, root length (≈30% increase), leaf area, and plant weight while reducing necrosis and chlorosis.

Speed breeding has been effectively applied to accelerate the development of spinach cultivars with improved nutritional quality, including higher iron and folate content, as well as resistance to diseases such as downy mildew**.**

Brassica Vegetables (Cabbage, Cauliflower, and Broccoli)

Brassica vegetable crops generally have longer breeding cycles due to their requirement for vernalization to induce flowering**.** However, modified speed breeding protocols that incorporate controlled temperature treatments and extended photoperiods can significantly shorten the breeding cycle.

Typical speed breeding conditions include a photoperiod of approximately 20 hours, with temperatures maintained around 22–24°C during vegetative growth, followed by appropriate vernalization treatments to induce flowering. While traditional breeding cycles for Brassica crops may require 6–8 months per generation, speed breeding can reduce this period to approximately 90–120 days, allowing three to four generations per year**.**

Speed breeding in Brassica vegetables has been used to accelerate the development of biofortified varieties, climate-resilient cultivars, and pest-resistant lines. The approach is particularly valuable in hybrid breeding programs where rapid development of parental lines is required.

Advantages and Limitations

Speed breeding offers several advantages in vegetable crop improvement. The most important advantage is the reduction in breeding time, as multiple generations can be grown within a single year. This significantly accelerates the development of new varieties with desirable traits.

Another advantage is the rapid development of pure lines in self-pollinated crops using techniques such as single seed descent. Speed breeding also enhances research in plant genetics, physiology, and molecular breeding by enabling faster generation turnover.

Furthermore, speed breeding allows breeders to respond quickly to emerging agricultural challenges such as new pests, diseases, and climate stresses. When combined with modern genomic tools, it can greatly improve the efficiency and precision of breeding programs.

Despite its advantages, speed breeding also has certain limitations. Establishing controlled environment facilities such as growth chambers and glasshouses requires significant investment. The cost of artificial lighting and temperature control may also be high due to energy requirements (Samantara *et al.*, 2022).

In addition, not all vegetable crops respond equally to extended photoperiods and controlled conditions. Some crops may require specific environmental conditions or may exhibit physiological stress under prolonged lighting. Therefore, careful optimization of growth conditions is necessary for successful speed breeding.

Future Prospects

Speed breeding is expected to play an increasingly important role in vegetable crop improvement in the future. Advances in controlled environment agriculture, energy-efficient lighting systems, and automation technologies are making speed breeding more accessible and cost-effective.

The integration of speed breeding with modern molecular breeding techniques such as marker-assisted selection, genomic selection, and genome editing will further enhance its potential in developing improved vegetable varieties.

Speed breeding can also support research on climate-resilient crops by enabling rapid evaluation of plant responses to environmental stresses. In addition, it can facilitate the development of nutrient-rich vegetable varieties that contribute to improved human health and nutrition.

As global demand for vegetables continues to increase, speed breeding will become an essential tool for accelerating crop improvement and ensuring sustainable agricultural production.

Conclusion

Speed breeding is a promising and innovative approach for accelerating vegetable crop improvement. By manipulating environmental factors such as photoperiod, temperature, and light intensity, this technique enables rapid plant growth and multiple generations within a year.

The adoption of speed breeding in vegetable breeding programs can significantly reduce the time required to develop new varieties with improved yield, quality, and stress resistance. Although certain limitations exist, ongoing technological advancements and integration with modern breeding tools are expected to enhance its efficiency and applicability.

Overall, speed breeding represents a powerful strategy for meeting the growing demand for vegetables and addressing future challenges in agriculture.

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