Speed Breeding and Its Applications in Crop Improvement

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It's a concept of extending the duration of plants daily exposure to light combined with early seed harvest to quickly from seed to seed by reducing the times of generation for some long day and day neutral crops. This approach has significant implications for crop improvement, including: (a) Faster Variety Development (b) Increased Genetic Diversity (c) Crop Adaptation to Climate Change (d) Enhanced Yield and Quality (e) Reduction in Resource Requirements (f) Rapid Response to Emerging Challenges (g) Improved Genetic Mapping and Understanding (h) Commercial Benefits

Speed breeding was first initiated by US NASA targeting to raise wheat in space using extended photoperiods or constant light and precise temperature in order to overdrive photosynthesis and hasten plant growth. Dr Lee Hickey and his co-workers were the first to adopt NASA Plan for the production of wheat and peanut at the University of Queensland, John Innes Centre and the University of Sydney in Australia.

Earlier approaches to hasten breeding cycles

Shuttle breeding: The objective of speeding the process by growing two successive plantings per year.

Double haploids technology (DH): Generated directly from pollen or egg cells, subsequently chromosome doubling to restore fertility and the normal diploid chromosome number.

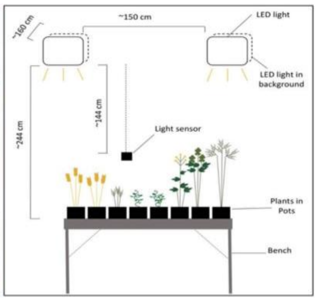
Need of speed breeding

The need of speed breeding in current era is very much essential because of various disadvantages in current plant breeding technologies, the present breeding technology is much slower process to develop variety it takes years to release a new variety and availability of variability among genotypes are depleting because of excessive self-pollination & homozygosity in plants. The biggest challenge of breeding higher yielding and more resilient crops is the inability to complete more generations in lesser time. Certain crop species, such as radish (*Raphanus sativus*), pepper (*Capsicum annum*) and leafy vegetables such as Amaranth (*Amaranthus* spp.) and sunflower (*Helianthus annuus*) responded positively to increased day length. Speed breeding of short-day crops has been limited because of their flowering requirements. It is possible to develop successive generations of improved crops for field examination *via* SSD, which is cheaper compared to the production of DHs. Plant–pathogen interactions, plant anatomy and flowering time can be studied in detail and repeated using the technology. For the photosensitive crops like soybean, speed breeding is not suitable to speed up the breeding cycles to overcome that a need powerful breeding technology to increase the pace of breeding technologies as well as developing much quality and new cultivars which helps to cope up current changing climate.

Speed breeding has a lot of potential to completely change present scenario of current plant breeding technologies by combining with state art technologies like with other molecular approaches, genome editing technologies like CRISPR-CAS9 saves lot of time and it helps the plant breeders snip out the yield reducing or other vulnerable traits from the crop and advancing the crop generation with rapid pace speed breeding can be done in diploid crops then polyploid crops because of their complex genomics. Speed breeding can also be utilized to boost up the transgenic approaches of crop improvement. Scientists are also applying speed breeding system to speed up the double haploid program. The approach has also been adapted for high density plant production systems for SSD programs. Generation time was shorter than for plants grown at lower density in previous speed breeding experiments. Higher density may cause stress or plant competition, lead to hasten flowering

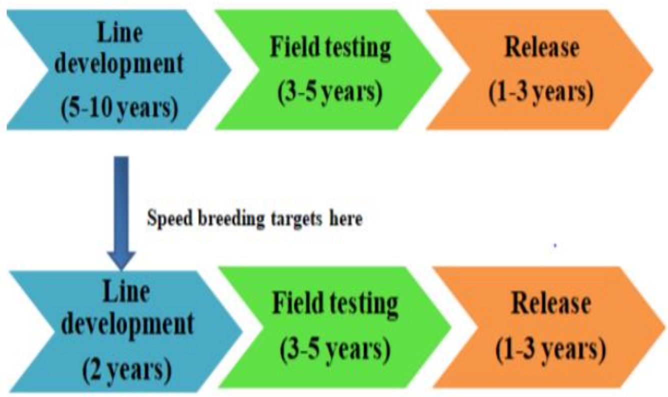
Basically, this experimental research was conducted in three methods they are Speed breeding I – Controlled environment chamber speed breeding. Speed breeding II - Glasshouse speed breeding conditions Speed breeding III - Homemade growth room design for low-cost speed breeding.

This breeding technique uses modified temperature conditions replacing the traditional artificial light like sodium vapour lamps or halogen lamps by LEDS light emitting diodes as a supplementary light source for extending photoperiodism and to speed up the crossing and inbreeding of varieties speed breeding protocols designed different for different species altering the light treatments and modifying temperatures need to be optimized subsequently .the optimal conditions to be followed in speed breeding in light spectrum that used PAR region of (400-700 nm) with mainstream focus on the blue red or far red regions of the spectra. A light/dark period was chosen over a continuous photoperiod to support functional expression of circadian clock genes. Specific photoperiod length of 22h with 2h of darkness is recommended to improve the plant health (for other species like wheat, barley, oat 18h photo period is enough). Optimum temperature regime should be applied its aids in stress recovery. In most of the conditions at UQ, a 12-h 22 °C/17 °C temperature cycling regime with 2 h of darkness occurring within 12 h of 17 °C has proven successful. Humidity, but a reasonable range of 60–70% is ideal.



Core goals of speed breeding

Need of this advance technology because of rapid growing population, climate change, rapid urbanization, depleting land are the major concerns to develop this technology if land is depleting, we need to increase the food production per acre or ha and developing horticultural crops and drought resistant crops and increase the genetic gain of the crop by adapting various technologies one such technology came in to existence is speed breeding. This Speed breeding accelerates generation time of major crop plants for research and breeding technology does need much need of land but it can advance the crop generation with rapid pace this technology will feed the future growing population.



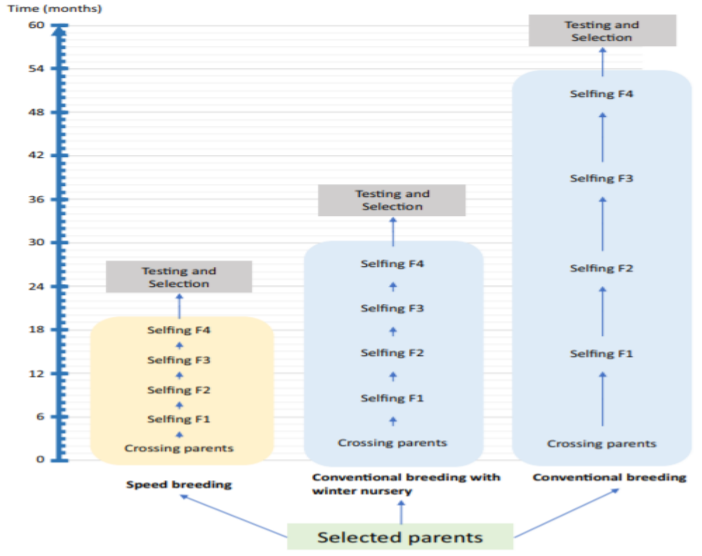


Fig 1 Schematic comparison of time required to develop elite lines from selected parents of peanut using speed breeding

Combining speed breeding technology with other state-art-technologies

1. Speed breeding and marker assisted selection: For genetically well-defined traits, speed breeding could be used to rapidly introgress genes or haplotypes into elite lines using marker-assisted selection. The speed breeding system is potentially relevant for the rapid development of RIL's which are essential for molecular marker discovery.
2. Speed breeding and Association mapping: To track and confirm the presence of target regions.
3. Speed breeding and genomic selection: Pyramiding of multiple traits and to enable selection for yield and grain quality traits. The speed breeding/SSD system is ideally suited to a backcrossing breeding strategy.
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5. Integration with high density plant production systems and transgenic approach

Challenges of Speed Breeding

1. Staff trained in the protocol
2. Adopting major changes to breeding programme design and operations
3. The need for long-term funding
4. Lack of trained plant breeders and breeding technicians
5. Inadequate infrastructure 6. Unreliable water and electricity supplies for sustainable operations.

Achievements

- DS Faraday, first wheat variety developed using speed breeding: High protein, milling quality with tolerance to pre harvest sprouting (PHS) (Tarek *et al.* 2018)

- Drought tolerance trait in Scarlett variety of barley was achieved within two years by taking four lines with a modified backcross method and speed breeding.
- YNU31-2-4 a Salt tolerant rice variety was developed with the help of speed breeding. Speed breeding surpasses "Shuttle Breeding" and produces three times a greater number of generations. With shuttle breeding, only two generations per year can be achieved, while with speed breeding, up to 6 generations can be obtained.

Potential advantages of speed breeding

1. Scientist can study this technology the way it deals with diseases and plant pathogen interactions shape and structure and flowering time and from the above we can know the growing cycle can be repeated every 8 weeks.
2. The quality and yield of the plants can be grown under controlled climate and extended day light conditions sometimes better than those of crops which are grown under normal glass house conditions.
3. In future this technology can be used in various crops and it many other applications it can applied to vertical farming gardens, horticultural crops.
4. Multi- environmental trail across years
5. Exploit gene bank accessions and mutant collection for rapid gene discovery
6. Rapid introgression genes into elite lines using Marker Assisted Selection and phenotypic selection in early segregating generations.

Limitations

1. Short-day (SD) plants require the photoperiod to be less than the critical day length to flower which could be at odds with SB conditions.
2. The SB procedures take place in an enclosed, artificial environment, which differs significantly from the field.
3. Early harvest of immature seed can interfere with the phenotyping of some seed traits.
4. There is no universal protocol of speed breeding because of diverse response of plant species to photoperiodic conditions.
5. Differential responses of various plant species when exposed to extended photoperiodic conditions.
6. Disease outbreak using controlled environmental conditions
7. The initial investment is high.

Future of speed breeding

Speed breeding likely to reduce generation time for other crop species, such as sunflower, pepper and radish which have been shown to respond well to extended photoperiod. Direct application of speed breeding protocols to short-day species such as maize or rice are unlikely to be successful. Advance in LED light technologies, provides opportunity to optimize PAR and customize the wavelength and intensity to suit different growth stages and plant species. The future of speed breeding holds promise and potential in several key areas: (1) Precision Breeding (2) High-Throughput Technologies (3) Data-Driven Approaches (4) Climate Resilient Crops (5) Customized Crops (6) Biotechnology Integration (7) Expanded Crop Variety Availability (8) Resource Efficiency (9) Global Collaboration (10) Regulatory Considerations (11) Consumer Preferences (12) Crop Diversity Conservation. Overall, the future of speed breeding is closely tied to advancements in science and technology, and it will continue to be a key driver of innovation in agriculture. This method has the potential to address the evolving challenges facing the agricultural sector, from climate change and population growth to the need for sustainable, resource-efficient, and resilient crop production.

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