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ROLE OF SPEED BREEDING IN CROP IMPROVEMENT

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Abstract:

Speed breeding is an innovative technique in crop improvement that aims to accelerate plant breeding cycles and shorten the time required to develop new crop varieties. This approach combines optimized growth conditions, such as controlled environment chambers, with enhanced light and temperature regimes to promote rapid plant growth and development. By manipulating the plant's growth environment, speed breeding facilitates the achievement of multiple generations within a single year, allowing breeders to evaluate and select desired traits more quickly. This review explores the role of speed breeding in crop improvement, highlighting its advantages, challenges, and potential applications in addressing global food security challenges. Key topics include the impact of speed breeding on genetic gain, trait selection, disease resistance, and the integration of molecular breeding techniques. Additionally, the potential implications of speed breeding for sustainable agriculture and the conservation of genetic diversity are discussed.

Keywords: Speed breeding, crop improvement, plant breeding, accelerated breeding cycles, controlled environment chambers, genetic gain, and trait selection.

Introduction

The increasing human population and climate change are the major hurdles faced by the global food security systems, and providing sufficient food for a growing population that will reach about 10 billion by 2050 is a huge challenge. Speed breeding reduces generation time required for cultivar development, release and commercialization. Speed breeding saves breeding time through rapid generation advancement.

The use of speed breeding techniques is a valuable approach to accelerate conventional plant breeding programmes. Hence, there is a necessity to breed higher-yielding cultivars by using an appropriate breeding strategy having rapid and fast genetic advances. Speed breeding is one of the technologies that enable the utilization of gene bank accession or mutants for rapid gene discovery and exploit them for future use.

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Initially, NASA started a research program in collaboration with national and international partners including the University of Queensland, the University of Sydney, and achieved success in growing wheat in space with the continuous supplement of light and other essential growing medium. Dr. Lee Hickey (University of Queensland, Australia) was inspired by the work of NASA, started research and coined a new breeding term “Speed breeding”. Speed breeding integrated with advanced techniques can lead to rapid trait discovery and has the potential for rapid genetic gain of the desired traits which are necessary for enhanced yield and crop production to feed future generations. The growing population may lead to a 60-80 % increase in demand for food by 2050. The changing environmental conditions have lead to a 20 % decrease in the potential yield of vegetable crops. The current scenario of genetic gain is only less than one % and hence, it is necessary to increase it up to two % to meet the projections. The slow improvement rate is attributed partly to the long generation times of crop plants. Crop breeding and advances in management practices have contributed substantially to the annual gain of 0.8–1.2 % in crop productivity.

Speed Breeding -Evolutionary Mile Stones:

NASA initiated a new concept of research for growing food crops in space to meet food requirements for astronauts. Plants that responded to continuous light supplements, expressed rapid growth and development than outer environments. The principle behind speed breeding is that when plants are grown with continuous light supplements they show accelerated growth and early maturity. In the 1980s, NASA in collaboration with Utah State University explored a new possible way for the faster and rapid growth of wheat in space (Hickey *et al*., 2019). This lead to the development of a new dwarf wheat cultivar “USU-Apogee” using rapid cycling through speed breeding protocol. Meanwhile, another milestone research was made by Russian scientists using “Space mirrors” which turned night into day at the earth for enhanced yield and crop productivity of food grains. Plant breeding plays a significant role in developing vegetable varieties that are high yielding, superior in quality, resistant to biotic and abiotic stress and that can sustain the effects of climate change (Jahne *et al*., 2020). Since developing cultivars by conventional methods are time-consuming a recently developed speed breeding protocol based on light-emitting iodides (LEDs) for supplying appropriate quantity and quality of light spectrum for rapid cycling in cereals and vegetable crops has great significance. Speed breeding accelerates more cycling or generations per year that facilitates rapid cultivar development. A schematic representation of time duration and generation advancement for conventional and speed breeding is presented in the Fig.1.1

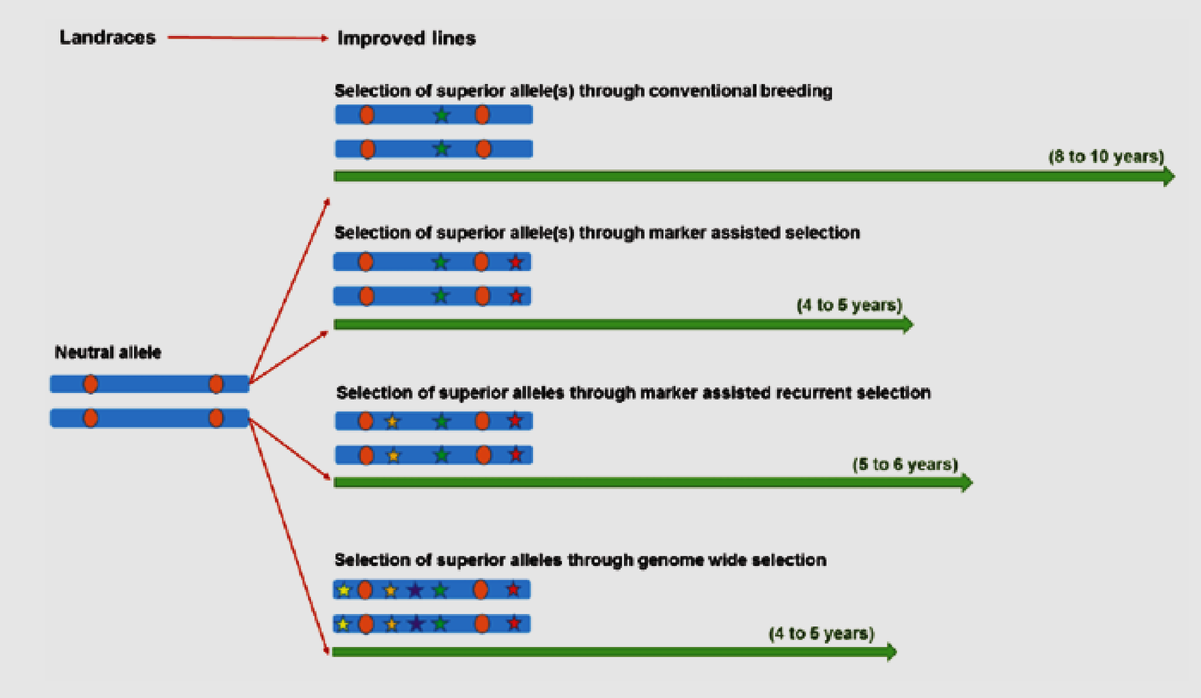

FIGURE 1.1 Schematic representation of total duration for conventional and speed breeding

SPEED BREEDING IN POTATO

Speed breeding protocol enables 4-6 generations per year with supplementary long photoperiod under glasshouse chamber, instead of only a single generation in the open condition. Potato speed breeding was carried out by giving extended lighting in controlled greenhouses to accelerate early growth and development, which lead to earlier flowering, fruiting, and faster seed maturity (Sood *et al.*, 2020). Simultaneous growing of tomato in aeroponics integrated speed breeding methods helped in year round production of disease-free mini tubers suitable for planting (Fig.1.2).

SPEED BREEDING IN TOMATO

Tomato acts as a model crop for biotechnological and molecular Research. Study on the effects of continuous light on growth and yield of tomato showed that continuous exposure to light resulted in chlorosis and necrosis on leaves and affected yield and quality. Moreover, continuous light supplement induced chlorosis and necrosis on tomato leaves. In an attempt to understand the performance of tomato upon exposure to continuous light, the studies on the tomato simulation model "TOMSIM" was carried out.

The results showed that an increased yield of about 22-24 % was realized in the greenhouse grown tomato introgressed with the CAB-13 gene, when grown with continuous light of 18 hours/day which enabled rapid growth, enhanced yield, and doubled the genetic gain.

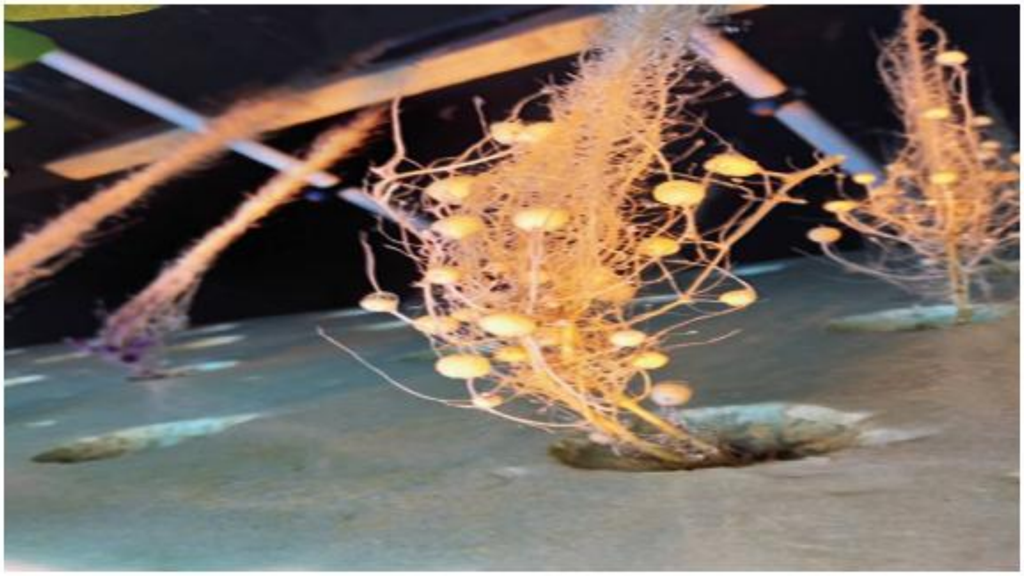

FIGURE 1.2 Disease-free mini tuber productions in the aeroponics system in potato

Solanum pimpenellifolium, (LA-1589) showed resistance to continuous light condition. Introgression of the CAB-13 gene, which gives the ability to tolerate continuous light, in tomato, eggplant, and potato could accelerate the speed breeding program. Comparison of RNA-Seq derived transcriptome analysis of light tolerant wild species and light-sensitive genotypes lead to the identification of chlorophyll a-b binding protein- CAB-13 gene, a putative candidate gene, which confers tolerance against continuous light. The study showed that the continuous light sensitive plants are enriched with carbohydrate metabolic process, chlorophyll biosynthetic process, photosystem -I reaction centre, and chlorophyll-binding; while the light tolerant plants have carbohydrate metabolic process, chlorophyll-binding, and heme-binding enrichment when exposed to continuous light. CAB-13 introgressed plants were similar to the normal plants in flowering truss appearance, fruit set, but were taller than the normal ones. Exposure to 16 hours continuous light in CAB-13 introgressed plants resulted in 20 % enhanced yield, than control plants (Arnon *et al.*, 2014). *Solanum neorickii, S. pennellii, S. habrochaites* and *S. chilense* are used as source of resistance to breeding for continuous light tolerance in cultivated tomato. Speed breeding program on solanaceous crops has been illustrated in the Fig.1.3.

FIGURE 1.3 Speed breeding program initiated at ICAR- IIHR, Bengaluru on eggplant and tomato (Personal communication, Ramavath Ramesh Babu, (2020)).

SPEED BREEDING IN ONION

Onion suffers from severe inbreeding depression as it is a cross pollinated, biennial plant (bulb formation occurs in one year, flowering and seed setting take place in the next year), which takes 10-12 years for varietal development. Onion grown in lower altitude requires 10-12 hours photoperiod for flowering, instead of 14-16 hours photoperiod required for those at higher altitudes (Brewster, 2008). Supplementation with far-red light and high-temperature 25-30˚C promotes bulb formation. In onion, speed breeding can hasten breaking bulb dormancy. Subjecting to 22-hours photoperiod using far-red light can accelerate bulb initiation within 45 days and results in rapid bulb maturity within 80 days instead of 5-6 months under normal conditions (Khosa and Dhatt, 2020). Speed breeding combined with double haploid breeding and genome editing technology accelerated rapid generation advancement, resulted in faster development of onion cultivars within 2-3 years. A new breeding method "Seed to Seed" method was proposed in the onion to accelerate rapid generation advancement within one year. Shuttle breeding strategy was proposed for shortening the generation cycle in onion in which required onion bulbs can be produced during Kharif season in north and central part of the country and then sent to higher hills on Himachal Pradesh and Jammu Kashmir to produce flowers. Hence, this strategy enables completing one cycle within one year and accelerates varietal development in onion (D'Angelo and Goldman, 2019). Speed breeding program in onion consist of (1)seed sowing in May, bulbs are harvested in September- October, (2) bulb dormancy breaking by using 20 % hydrogen peroxide and subjecting to 20˚C in the greenhouse (October) with continuous supplementation of 16 hours photoperiod and vernalization for inducing earlier flowering, (3) earlier scape emergence takes place in the month of February-March, (4)optimum temperature should be maintained about 22-24˚C during the flowering period, which results in earlier seed maturity in the month of April-May.

Hence, speed breeding integrated with the greenhouse technology enables rapid generation advancement within one year. A schematic representation of speed breeding protocol for onion is given in the Fig.1.4.

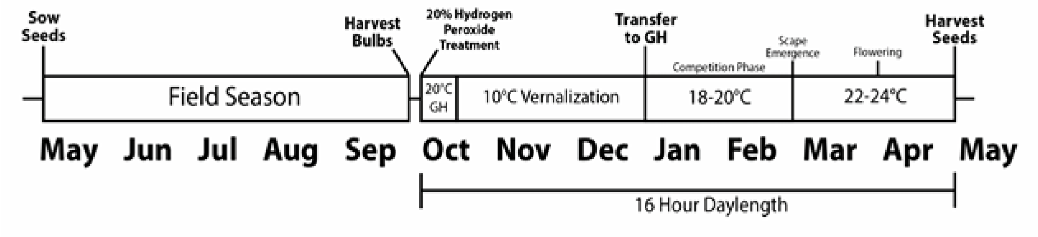

FIGURE 1.4 Schematic speed breeding program in onion for rapid generation advancement

SPEED BREEDING IN LEGUME CROPS

As an important source of dietary proteins, consumption of legume crops is essential for proper growth and development. Cool season legume crops chickpea (*Cicer arietinum*), faba bean (*Vicia faba*), lentil (*Lens culinaris*), pea (*Pisum sativum*), and some warm-season legumes including common bean (Phaseolus vulgaris), cowpea (*Vigna unguiculata*), pigeon pea (*Cajanus cajan*), soybean (*Glycine max*), and groundnut (*Arachis hypogaea*) are the chief source of dietary proteins in developing countries and plays an important role in supplying protein-calorie requirement in the diet of the people. Speed breeding for rapid generation advancement and fast incorporation of desired traits has received much attention legumes crops (Luckow, 2003). Combining biotechnological tools such as in vitro and in vivo techniques along with speed breeding, enabled for achieving 6 generations per year instead of 2-3 generations in conventional breeding programme. In Pea, speed breeding and successive seed to seed method facilitated reduction of mean duration of one generation to 67.2 ± 4.6 days; while it takes 146 ± 4.3 days normally. An optimum temperature of 20˚C with light supplement of 16 hours using far-red light through 400 W sodium vapour lamp accelerated faster vegetative growth; ultimately lead to a faster seed maturity within 65-70 days (Ochatt *et al*., 2002).

SPEED BREEDING PROTOCOL FOR SHORT DAY CROPS

Generally, light quantity and quality plays a major influence on growth and development, flowering, and seed maturity (Watson *et al*., 2018). In soybean, adjusting the photoperiod to 10 hours with a blue-light enriched, far-red-deprived light spectrum facilitated the growth of short, sturdy soybean plants that flowered 23 days after sowing and matured within 77 days, thus allowed up to five generations per year (Jahne *et al*., 2020). In amaranthus and rice, early flowering can be achieved using far-red light spectrum. Optimum temperature was maintained at 28˚C with 80 % relative humidity during entire speed breeding program in the growth chambers. Recently, (Jahne *et al*., 2020) developed a speed breeding protocol in short day crops including soybean, rice, amaranthus, and sorghum, who proposed an "ecotune" LED growth chamber with light intensity ranges from 556-574 Lux/ m2, photoperiod of 10 hours light, 14 hours dark which accelerated growth and development. Generally, long photoperiod (>12 hours) may hinder growth and early flowering in short days plants (photoperiod sensitive), but facilitated accumulation of carbohydrate therefore, speed up seed production (Chatterton and Silvius, 1979). Development of phytochrome deficient genotypes in short day crops like soybean, sorghum, amaranthus, and rice facilitated early flowering, and advanced seed maturity (Childs *et al*., 1997). Far-red light enhanced the development and transition of inactive phytochrome to active phytochrome. The quality of light has a major influence on growth and development; blue light (450 490nm) accelerated the rate of photosynthesis during dark conditions, while far red light facilitated early flowering in short and long day crops (Childs *et al*., 1997, Craig and Runkle, 2013). Far-red light (>700 nm) does not influence flowering, but sometimes accelerated unwanted and deformed morphology especially in soybean. Jahne *et al*., (2020) reported that green light (500-560 nm) did not show a pronounced influence on flowering and plant height in soybean. Speed breeding protocol cannot be readily interchanged from one short day crop to another. Therefore, it is necessary to standardize genotype independent speed breeding program for short day crops. The major objectives of the speed breeding program are enhancing early flowering, early maturity, and fast germination of seeds. Speed breeding is a powerful tool to accelerate crop research and rapid generation advancement in short-day crops. Therefore, it is necessary to develop and design crop specific lighting patterns separately for soybean, rice, amaranthus, and sorghum for hastening flowering, early maturity, and rapid generation advancement. Speed breeding enables achieving up to five to six generations per year instead of 1-2 generations per year in conventional breeding, facilitated double genetic gain and also accelerated introgression of the simply inherited traits or monogenic traits (Hickey *et al*., 2019). Representation of time required for speed breeding in short day crops is given in the Fig.1.5.

SPEED BREEDING- A POTENTIAL TOOL FOR DEVELOPMENT OF VARIETIES

Continuously increasing human population is predicted to reach 10 billion by 2050. This gives alarm signals for plant breeders for increasing food production in the future. Therefore, it is necessary that we should invent some new breeding methods that can accelerate genetic gain (Watson *et al*., 2018). Dr. Lee Hickey, a geneticist and plant breeder at the University of Queensland, Australia developed a new breeding tool "Speed breeding" that could accelerate genetic gain, and help to meet our future food demands. Climate changes, which lead to frequent occurrence of drought, flood, high temperature, cold, and recurrence of biotic, abiotic stresses, are major threats to food security. To mitigate these challenges, conventional breeding methods integrated with new genomic tools such as high throughput

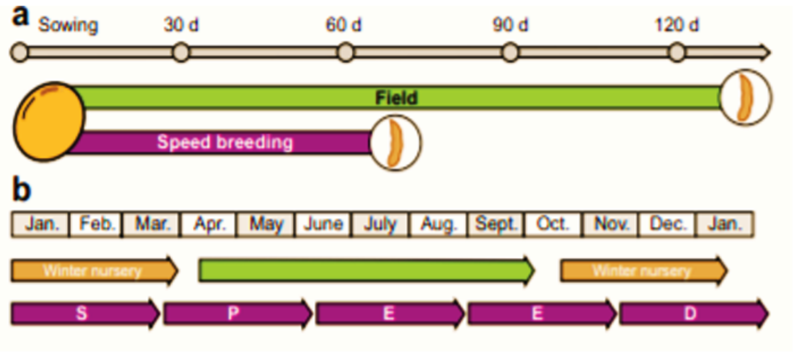

FIGURE 1.5 Representation of speed breeding for short day crops (a)time required for one generation from sowing to maturity(b) speed breeding (one winter nursery) enables for growing 2-3 generations that facilitated 5-6 generations in one year. Jahne et al., (2020).

genotyping and phenotyping with DNA marker technologies enable faster genetic gain and accelerate varietal development (Hickey *et al.*, 2019). Speed breeding is an inspired space breeding technology; which enables growing plants more quickly, efficiently, and cheaply for achieving rapid genetic gain (Ghosh *et al.*, 2018). Currently, climate change, especially drought imposes a major challenging problem for food production globally. (Hickey *et al.*, 2019) proposed extensive root phenotyping techniques and identification of QTLs which are responsible for root morphology, root architecture, and deeper root penetration so that these can be used for developing drought-resistant cultivars. Hickey *et al.*, (2019) developed speed breeding protocol for long day and day neutral crop plants such as wheat, barley, and canola. Speed breeding protocols are in their infancy in short-day crops, because they require photoperiod to be maintained below the critical day length. Bill and Melinda Gates Foundation, in collaboration with the International Crop Research Institute for Semi-Arid Tropics (ICRISAT), has developed a speed breeding protocol for the growing of short-day crops to like sorghum, millets, and pigeon pea to accelerate early flowering and rapid generation advancement. Generally, sorghum, millets, and pigeon pea are important crops in the semi-arid, arid regions owing to low water requirement, tolerance to abiotic stress and suitability for smallholder farmers in Africa and Asian countries. Developing an optimized speed breeding protocols in these crops is essential to meet the requirement of food demand in these regions. Pigeon pea (*Cajanus cajan* (L.) Millsp) is an important leguminous crop; photo-sensitive and requires prolonged darkness for flowering and fruiting. Pigeon pea is photo-sensitive and it requires less than 10 hours light period for induction of flowering with ambient temperatures (18-25° C). Recently, breeding attempts have been focusing on the identification of QTLs, and developing markers associated with the genes for photo-insensitivity that enable growth in the prolonged light conditions which facilitates rapid generation advancement through speed breeding.

INTEGRATING SPEED BREEDING WITH OTHER TECHNIQUES OF BREEDING

SHUTTLE BREEDING-

Other innovative breeding techniques which can accelerate genetic gain and rapid generation cycling are shuttle breeding, double haploid breeding, and embryo rescue. Normen E. Borlaug began growing two crops of wheat a year in contrasting growing conditions. As a result, Borlaug's “shuttle breeding” produced highly adaptive wheat, yielding twice the production potential. Borlaug’s breeding innovation had the objective of speeding the process by growing two successive plantings per year—one during summer in the low-soil fertility, rain fed areas at Chapingo and Toluca, in high altitudes, and another during the winter season almost two thousand kilometres to the north, in the irrigated area near sea level in the Yaqui valley in Sonora, where growing conditions and soil fertility were much more favourable.

DOUBLE HAPLOID BREEDING-

Doubled haploids refer to the diploid lines which are obtained by doubling the chromosome number of a haploid line by colchicine treatment. Such condition is referred to as doubled haploids. (Blakeslee *et al.*, 1922) first identified naturally occurring haploids of Datura stramonium and subsequently, natural haploids of many other plants were reported. The haploid embryo can arise from an egg cell (Gynogenesis) or a gametophytic cell other than the egg cell (apogamy) or a male gamete (androgenesis). The observations in Datura were soon reproduced for tobacco. Double haploid is simply and highly attracted by plant breeders because it is simple and one step leading to production of rapid homozygous line. For development of homozygous line in cucumber, it will take 6-7 generations (4-5 year) by conventional methods while by using double haploid approaches it could be achieved in 1-2 years.

Conclusions

Continuously increasing human population is predicted to reach 10 billion by 2050. In addition, climate changes, which lead to frequent occurrence of drought, flood, high temperature, cold, and recurrence of biotic, abiotic stresses, are major threats to food security. These give alarm signals for plant breeders, for increasing food production in the future. To mitigate these challenges, conventional breeding methods should be integrated with speed breeding technology and new genomic tools such as high throughput genotyping and phenotyping with DNA marker technologies for enabling faster genetic gain and accelerate varietal development. Since, developing cultivars by conventional methods are time-consuming; a recently developed speed breeding protocol based on light-emitting iodides (LEDs) for supplying appropriate quantity and quality of light spectrum for rapid cycling in cereals and vegetable crops has great significance. Speed breeding protocol enables 4-6 generations per year with supplementary long photoperiod under glasshouse chamber, instead of only a single generation in the open condition. Speed breeding reduces generation time and rapidly generates homozygous lines through single seed descent, which in some species may be cheaper than generating double haploids, thus facilitates genetic gain for key traits and allow rapid production of improved varieties. Combining genomic selection and genome editing with speed breeding will provide strong incentives for scientists to perform research, thus accelerating crop improvement and variety development.

References

1. Anitha, P., Anu, G.K and Peter, K.V. 2022. *Horticulture Science for Doubling Farmers' Income*. Brillion Publishing. New Delhi. 1-20.
2. Blakeslee, A.F., Belling, J., Farhham, M.E and Bergner, A.D. 1922. A haploid mutant in the Jimson weed *Datura stramonium*. *Science*. 55: 646-47.
3. Brewster, J.L. 2008. Onions and other vegetable Alliums. 2nd ed. CABI: Oxfordshire.
4. Chatterton, N.J and Silvius, J.E. 1979. Photosynthate partitioning into starch in soybean leaves: I. Effects of photoperiod versus photosynthetic period duration. *Plant Physiology*. 64: 749–753.
5. Childs, K.L., Miller, F.R., Cordonnier-Pratt, M. M., Pratt, L.H and Morgan, P.W. 1997. The sorghum photoperiod sensitivity gene, Ma3, encodes a phytochrome B. *Plant Physiology*. 113: 611–619.
6. D'Angelo, C.J and Goldman, I.L. 2019. Annualization of the long day onion breeding cycle through threshold vernalization and dormancy disruption. *Crop Breeding, Genetics and Genomics*.1. e190009. https://doi.org/10.20900/cbgg20190009
7. Ghosh, S., Watson, A., Gonzalez-Navarro, O.E., Ramirez-Gonzalez, R.H., Yanes, L., Mendoza-Suárez, M., Simmonds, J., Wells, R., Rayner, T., Green, P., Hafeez, A., Sadiye Hayta, S., Melton, R.E., Steed, A., Sarkar, A., Carter, J.L., Lord, J., Tester, M., Osbourn, A., Moscou, M. J., Nicholson, P., Harwood, W., Martin, C., Domoney, C., Uauy, C., Hazard, B., Wulff, B.B.H and Hickey, L.T. 2018. Speed breeding in growth chambers and glasshouses for crop breeding and model plant research. *Nature Protocols*. 13: 2944–2963.
8. Hickey, L.T., Hafeez, A.N., Robinson, H., Jackson, S.A., Leal-Bertioli, S.C.M., Tester, M., Gao, C., Godwin, I.D., Hayes, B.J and Wulff, B.B.H. 2019. Breeding crops to feed 10 billion. *Nature Biotechnology*. 37: 744-754.
9. Jähne, F., Hahn, V., Würschum, T and Leiser,W.L. 2020. Speed breeding short-day crops by LED controlled light schemes. *Theoretical and Applied Genetics*. 133: 2335–2342.
10. Khosa, J.S and Dhatt, A.S. Improvement of Onion Through Accelerated Approaches. 2020. In Accelerated Plant

Breeding; Gosal, S.S.; Wani, S.H., Eds; Springer Nature: Switzerland, Vol. 2; p 445.

11. Ochatt, S.J., Sangwan, R.S., Marget, P., Assoumou Ndong, Y., Rancillac, M., Perney, P and Röbbelen, G. 2002. New approaches towards the shortening of generation cycles for faster breeding of protein legumes. *Plant Breeding*. 121: 436—440.
12. Sood, S., Bhardwaj, V and Sundaresha, S. 2020. Major Paradigm Shifts in Potato Breeding. In *Accelerated Plant Breeding*; Gosal, S.S.; Wani, S.H., eds; Springer Nature: Switzerland. 2: 1-16.
13. Watson, A., Ghosh, S., Williams, M.J., Cuddy, W.S., Simmonds, J., Rey, M.D., Md Hatta M.A., Hinchliffe, A., Steed, A., Reynolds, D., Adamski, N.M., Breakspear, A., Korolev, A., Rayner, T., Dixon, L.E., Riaz, A., Martin, W., Ryan, M., Edwards, D., Batley, J., Raman, H., Carter, J., Rogers, C., Domoney, C., Moore, G., Harwood, W., Nicholson, P., Dieters, M.J., DeLacy, I.H., Zhou, J., Uauy, C., Boden, S.A., Park, R.F., Wulff, B.B.H and Hickey, L.T. 2018. Speed breeding is a powerful tool to accelerate crop research and breeding. *Nature Plants*. 4: 23-29.