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SPEED BREEDING TO HASTEN THE BREEDING PROGRAMMES IN CHICKPEA CROP (*CICER ARIETINUM*) – A REVIEW

K. Anandhi*, L. Karthiba, L. Rajendran and N. Manivannan

Department of Pulses, DCPBG, TNAU, Coimbatore, Tamil Nadu, India
***Corresponding author:** K. Anandhi, Email : anandhi.k@tnau.ac.in

ABSTRACT
Development of a new variety of homozygous nature in a self-pollinated crops requires around ten years in season specific crops as it requires several years of selfing as a single crop alone can be raised in a year while in other pulse crops like blackgram in which four seasons can be raised in year. Off season nursery which increases the number of generations could forward only two generations in a year in chickpea and again the yield is very less in the offseason and selection could not be possible. In some crops, doubled haploids could be exploited which is not reported in chickpea (*Cicer arietinum*). Though some advancement has been brought by mutation and selection which aided in the development of kabuli type of chickpea still low productivity is reported. Recent advances with use of speed breeding technology could result in rapid advancement of six generations as reported in chickpea and use of single seed descent could accelerate breeding in chickpea. The speed breeding technology mainly harnessed in controlled environment with optimized photoperiods could aid in breaking yield plateau. Hence this review will focus speed breeding as the strategy to conserve time and develop trait specific cultivars to suit changing climatic scenario and yield. The breeding cycle could be lessened by the introduction of speed breeding techniques which is reviewed in detail in this article.

KEYWORDS: Chickpea, speed breeding and rapid generation advancement

INTRODUCTION

Chickpea (*Cicer arietinum*) is an important legume crop widely cultivated particularly during Rabi season. This cool season conditioned annual pulse crop belongs to the Cicerae tribe of Fabaceae family. The *Cicer* genus has annual and perennial types to a tune of nine and thirty-four species respectively with a variety of growth habits but adapted to cool season alone. The only cultivated species among all listed above is *Cicer arietinum* type (Singh *et al.,* 2008). This globally cultivated crop has occupied an area 14.81 mha around the world during 2022 with grain production of 18.09 mt and a productivity of 1222 kg/ha. The largest producer of chickpea is India (FAOSTAT, 2024) contributing to considerable portion in area and production particularly adapted to rainfed farming where majority of the crops finds hard to thrive. The major chickpea growing parts of India occupies central and peninsular part accounting for maximum acreage and production particularly in the states of Madhya Pradesh, Uttar Pradesh, Rajasthan, Maharashtra and Andhra Pradesh (Goyal et al. 2011). Chickpea grown preferably in temperate zones as rainfed and hence loam and fertile sandy loam having good drainage facilities happens to be best suited agro climatic condition (Rao et al., 2010).

Being a legume crop, its cultivation enriches soil fertility due to formation of nodules harbouring rhizobia for fixing nitrogen especially in rainfed regions (Katerji et al. 2001), (Unkovich *et al.,* 2010). The nutritional advantage of pulses lies in the protein content which ranges between 17-31% in chickpea which also contains lysine, isoleucine, leucine, phenylalanine and valine as essential amino acids (Karim and Fattah, 2006). Pulses are known for their antinutritional factors including vicin in *Vicia faba*, oxalyl diamino propionic acid in lathyrus and trypsin inhibitors in *Glycine max* but cicer is devoid of any such factors (Williams and Singh 1987). Chickpea might have high nutritive and dietary benefits and may reduce the human ailments like cardio vascular disease, digestive diseases, type 2 diabetes and few cancers (Jukanti *et al.,* 2012).

Based on distinguishable seed characteristics, the chickpea is classified into two major types *viz.* Desi and Kabuli types. The desi types are identified by its small, dark (mostly green, brown or black seeds) which are angular shaped ones. The kabuli types are having contrasting characteristics as compared to desi. The kabuli seeds are large, cream and rounded with smooth coat, (Naghavi and Jahansouz, 2005; Iqbal et al., 2006). Beyond seed characteristics these two types also showed variation in vegetative and reproductive morphology. The contrasting nature especially bestowed in the colour of aerial parts including flower (Upadhyaya *et al.,* 2008). The vegetative parts mainly comprising of stem, branches and leaves of dark green nature in desi types while these aerial parts are characterized with light green nature in kabulli types of chickpea which is prime in classification of different types of chickpea.

The desi types are primitive and have more adaptation to biotic and abiotic stress conditions but fetches poor price in market as compared to kabuli types. A chickpea study conducted under both the rainfed and irrigated ecosystem revealed that oxalic acid, threonic acid, inositol, maltose, and L-proline are the metabolites accumulated

significantly increased levels in desi types and hence these osmoprotectants greater accumulation triggering inositol phosphate metabolism is the prime defence mechanism that fights against moisture stress in chickpea (Nisa et al., 2020)

Chickpea is known to have a narrow genetic base with a genome of size 738.09Mb (Varshney *et al.,* 2013). Researchers face many challenges due to this limited diversity in chickpea breeding especially while generating resistance to abiotic and biotic stresses. Through substantial efforts for identification and characterization the availability of donors for resistance have been reported by many researchers at various time. The widely utilised sources of resistant donors were listed for ascochyta blight, botrytis grey mould, fusarium wilt, sclerotia stem rot and chickpea rust by Haobing Li et al., (2015) and donors for Phytophthora root rot resistance was reported by Knights et al., (2008) and dry root rot resistance by Gurha et al., (2003). In addition to biotic stress breeding, significant achievements have been made in abiotic stress tolerance too. Drought, heat and cold stress resistant donors were listed along with basis of tolerance by Rani et al., (2020).

Though narrow genetic base is reported in chickpea global research have paved the way for identification of diverse donors for utilization in crop improvement programmes. These sources could laid foundation for pre breeding and introgression programmes aimed at combating global climate change and to make chickpea withstand multiple biotic and abiotic stresses.

Introgression of these donors is required for accumulation of stress resistance gene in chickpea and thereby need many generations of growing chickpea which in turn requires several years as the chickpea crop requires a span of about 90 days for maturity and again it is season bound unlike the other pulses. For instance, in blackgram which matures in around 70 days could be grown in four seasons (Reddy et al., 2022) in a year yielding the homozygosity in two years or so. In addition, the climate change threats are increasing and leads to modify the yield contributing traits. This necessitates development of biotic and abiotic resistant cultivars along with enhanced quality and increased yield. This could be achieved by combining donors of various parameters and reduction in breeding cycle is the need of the hour as new threats are posed every now and then.

Breeding approaches in chickpea

The chickpea crop could be cultivated in rabi season only in the prevailing environment as its prerequisite is cool climate which alone favours its growth and development. The history of cultivation of chickpea initiated with the cultivated species *Cicer arietinum L*., which forms the basis for domestication. *Cicer arietinum* is an annual crop and the wild species of Cicer comprises of nine annuals, thirty-three perennials and single unspecified taxa comprising of 43 recognized species (Goyal et al., 2011). The wild species are reported to have valuable biotic and abiotic stress resistance genes which is one of the major bottleneck in chickpea production. The prebreeding of chickpea with wild species would impart stress related resistance and would augment highly for broadening the narrow genetic base of chickpea (Mohar et al., 2016).

Essentially these augmentation efforts are becoming increasingly relevant in relation to climate change with increasing temperature, unpredictable rainfall, aggravation of minor biotic stress to major ones and emergence of new pest and diseases pose serious threats to agricultural sustainability. Using the aggregation and pyrimiding of multiple resistance genes from diverse parentage crop improvement programme can be designed for development of climate resilent chickpea to ensure food and nutritional security in the future decades.

Evolutionary factors like mutation and selection is believed to have combined action for the evolution of kabuli types from desi type in chickpea (Jana and Singh, 1993). Knowing the genetic architecture of the characters to be improved is a pre requisite for deciding the breeding method for any particular crop improvement (Priyadarshan, 2017). Being a self-pollinated crop additive effect through polygenes will have more influence on majority of the characters. The yield contributing characters showed heritability varying from moderate to low in chickpea (Tubabicer and Sakar 2008; Joshi et al., 2018). The characterization of these genes showed presence of numerous and complex inheritance having highly affected by environment (Krishnamurthy et al., 2010). Inspite of these challenges, substantial improvement in chickpea has been achieved (Rani et al., 2020; Gupta et al., 2010) through various breeding programmes such as introduction, mutation and hybridisation (Acquaah, 2015). In chickpea, germplasm sharing at international level and gene incorporation through continuous introgression from diverse genetic resources which include wild species and landraces have greatly improved the genetic diversity (Bajaj et al., 2015; Gaikwad et al., 2020). The wide hybridization involving *Cicer anatolicum* and *Cicer reticulatum* has contributed greatly towards enhancing seed yield (Maruf et al., 2019)

Several breeding approaches like introduction, mutation, hybridization and marker assisted selection have significantly contributed for improvement in chickpea over the years. Among these the hybridization and mutation breeding have more impact in creating diversity but they require advancement upto six generations in order to obtain stable homozygous lines which could be released as new varieties. The major bottleneck that hinders chickpea breeding is the slow pace of generation advancement that is only one generation can alone be completed in a year under natural condition. Advancing the generations using off season nursery results in increase to only two generations annually. Use of doubled haploids for homozygous line development which could obtain completely homozygous lines in a year is reported in various crops (Ren et al., 2017) for which methodology is not reported in chickpea.

Lengthy breeding cycles and a smaller number of generation advancement is a major reason for poor advancement in crop improvement programme (Pandey et al., 2022). Traditional breeding tools might not be adequate to meet the growing demands of food and agriculture and ensure nutritional security in the era of global climate change.

To overcome the shortcomings of traditional breeding tools, the modern breeding tools like speed breeding is being increasingly adopted. This aids in acquiring rapid genetic gain in several crop species (Lamichhane et al., 2022). Advent of speed breeding technology have paved way to grow crops in artificial condition with controlled temperature and photoperiod in which upto six generations per year could be advanced in chickpea (Watson et al., 2018). This advancement of generations could offer immense potential to shorten the breeding cycle and integrating this with other modern tools such as molecular markers and genomic selection, chickpea improvement programmes could be significantly strengthened. Hence this review highlights strategic utilization of speed breeding which is highly advantageous and promising approach to overcome constraints in traditional breeding methods and accelarate chickpea crop improvement.

Speed breeding technology

The concept of speed breeding traces its origin back to experimental studies on plant growth under controlled environmental condition. The development of dwarf wheat line under continuous light exposure by Utah State University in collaboration with National Aeronautics and Space Administration (NASA) marked a significant milestone for utilisation of controlled condition in agriculture. The experiment demonstrated the modality for growing crop by manipulation of light regimes and by controlling other environmental conditions. In addition, Russian Scientists suggested this for application in agriculture (Hatfield and Prueger, 2015). During the last decade of 20th century, the University of Wisconsin enhanced the agricultural productivity by utilising the light emitting diode (LED) lights in crop proliferation in artificial environment to make it more efficient and affordable (Hickey et al., 2019).

During 2003, University of Queensland utilized this protocol to enhance wheat breeding and named it as “speed breeding” (Hauston et al., 2020) thus designing a new way to shorten the life cycle dramatically and advance generation rapidly. This soon became a transformative approach in plant breeding and crop improvement programmes. The concept further evolved by utilization of specialised procedures for flower induction in plants artificially which could lower the spatial and temporal requirements. This in turn reduces the cost and time for inbred development significantly (Hussain et al., 2023). Speed breeding had been developed for wheat and barley in the cereals (Watson et al. 2018) to a wide array of crops across the plant taxa. In pulses its successful application was first reported in lupin (Croser et al. 2016), lentil and broad beans (Mobini et al. 2015; Lulsdorf and Banniza 2018) and among the spices in clover (Pazos-Navarro et al. 2017). The scope has been advances in *Amaranthus* spp. (Stetter et al. 2016; Joshi et al. 2018) among the leafy vegetables and even extended to fruit crops such as apple (van Nocker and Gardiner 2014) and chestnut (Baier et al. 2012) showed its versatility in application across annual to perennial type of plant species

Thus speed breeding technology originally conceived as a space experimental approach to study the possibility of plant growth with induced variation of environment by controlling various plant growth promoting factors has now emerged as a revolutionary tool for acceleration of rapid generation advancement in crop improvement programmes. The compression of breeding cycles could contribute more for spatial and temporal advancement of plant generation and to produce new varieties in various crops to address the challenges posed by global climate change and to ensure food and nutritional security with climate resilient agriculture.

Speed breeding in chickpea

In a year three generations were advanced by researchers using short season environments was the first breakthrough report in chickpea for rapid advancement (Gaur *et al.,* 2007). This achievement marked a crucial step towards the reduction of long breeding cycle in chickpea using traditional breeding approaches. Of late speed breeding is a very useful tool for reducing life cycles and to produce valuable material as it would allow chickpea breeders to take a greater number of generations in a year (Hickey *et al.,* 2019) through multiple breeding cycles against a single season crop. Utilizing speed breeding upto seven generations could be grown in a year thereby the homozygosity could be attained in one year as against to six to seven years with the conventional methods (Watson *et al.,* 2018). This would compress the timeline for development of inbred lines and achieve it in a single year. Further it was also reported that speed breeding methodology can aid in advancement of 4-6 generations in a year which would contribute to enhance genetic gain in pulse breeding (Varshney *et al.,* 2013).

A major advantage of this approach lies in its compatibility with various crop breeding methods. Different selection procedures such as 1) SPS (single plant selection), 2) SPD (Single pod descent) and 3) SSD (Single seed descent) can be combined effectively with speed breeding to reduce the time required to advance breeding material and efficient resource usage could be attained (Hickey *et al.,* 2017).

1) Single Plant Selection method (SPS)

In various crops, different characters has been improved effectively using single plant selection as compared to other selection methods solely due to the selected genetic background. Various instances where single plant selection has been used efficiently are improving yield in wheat (Thakare and Qualset 1978), yield in durum wheat (Mitchell et al., 1982), lentil seed yield in organic farming (Vlachostergios et al, 2011) for chickpea fusarium wilt resistance (Haji-Allahverdipoor et al. 2011) for lentil anthracnose resistance (Shaikh et al., 2013) and against numerous tomato diseases (Hanson et al., 2016). The numerous diseases comprise yellow leaf curl, late blight, bacterial wilt, late spot, fusarium wilt and tobacco mosaic virus. Single plant selection was found to be efficient in screening for dry root rot caused by *Phytophthora medicaginis* as reported by Miranda (2019). These studies proved that single plant selection can be effectively utilized for qualitative traits like yield and stress resistance

where controlled condition could empower with accelerated breeding and shorten the breeding cycle with early fixation of superior genotypes with desirable traits.

2) Single pod descent method (SPD)

Single pod descent method is advancing single pod for a plant without selection. This method suits well for pulses other than chickpea where number of seeds per pod is non single as the germination and other losses can be met by forwarding more than one representative seed for a plant. The advantage is better genetic representation and retention of genetic variability (Destro et al., 2003), reduced sampling error (Singh et al., 2003), and compatibility with speed breeding (Wanga et al., 2021).

A comparison was made between single seed descent method, single pod descent method and bulk method by Funada et al., 2013 and concluded that all methods are equally efficient and the method selection could be based on amount of inputs available and requirement of seeds at harvest.

3) Single seed descent method (SSD)

Fixation of genes in breeding lines and attaining of homozygosity could be achieved rapidly by using SSD which is a modification of traditional breeding methods. In this method a randomly selected single seed per plant is advanced during early segregating generations (Goulden 1939). The method is also named as modified pedigree method and the advantage is rapid generation turnover as multiple generations per year can be raised (Brim 1966) The single seed descent method was observed to be as efficient as, or even superior to the Bulk (BP), Pedigree (PD), and doubled haploid methods in several crop species, including soybeans (Boerma & Cooper, 1973; Empig & Fehr, 1971), oats (Kaufmann, 1971), wheat (Knott & Kumar, 1975; Tee & Qualset, 1975), and barley (Park et al., 1976). In addition, this method was found to be less affected by natural selection and sampling errors than bulk method (Roy, 1976). However, plant losses across generations due to poor germination, mortality, or failure to produce a single seed can alter the genetic composition of SSD populations (Martin et al., 1978). A computer simulation by Casali & Tigchelaar (1975) indicated that pedigree selection is most effective at high heritability levels, whereas SSD performs best under low heritability conditions. Modern SSD techniques allow breeders to advance up to three generations per year in most grain legume improvement programs. On inclusion of speed breeding upto seven generations can be advanced in a year

The fundamental principle that lies behind speed breeding is mainly through creation of a synthetic growth environment with extended daylight hours for the advancement of generations utilising this modern breeding method (Ren *et al.,* 2017). Manipulating photoperiods for early flowering induction by use of artificial light and advancing the seed to seed interval with the concept of immature seed germination aids in shortening of seed-to-seed cycle and thereby advancing more generation per year in chickpea (Fikre *et al.,* 2019). The temperature requirement is 25±1°C throughout the growth cycle of chickpea and the light intensity needed is 870 lm for 12 hours upto flowering after which darkness is required and combined with germination of immature seeds seven generations could be forwarded in a year (Samineni et al. 2019).

Hence, the integration of speed breeding technology with the other modern breeding strategies offers a new platform holding a promise for tremendous crop improvement. This is brought by drastically reducing the time requirement for breeding cycle, accelerating the period required for attaining homozygosity and provides an innovative pathway to rapidly advance generations to create new varieties suitable to combat global climate change.

Genetic gain improvement

Crossing genotypes that are diverged but are complementing parental lines for desired traits followed by selecting superior offsprings in subsequent segregating generation is the conventional breeding strategy primarily used in pulses and other crops to evolve improved crop strain (Breseghello and Coelho 2013). This approach relies on exploiting natural variation and recombination to assemble improved gene combinations into new varieties. However, despite the success achieved in this conventional pulse breeding it has a drawback in being a time-consuming resource intensive procedure typically require ten to fifteen years for development of a new variety using traditional methods (Ahmar *et al.,* 2020). Breeding pipeline generally involves large segregating population at initial stages of line fixation with numerous lines and moves to few advanced small subset of promising cultures at the end of breeding cycle (Lenaerts et al. 2019). This gradual narrowing of populations is essential for fixation of desirable characters, but it inherently a very slow process which takes very long duration for achieving overall breeding progress. The increase in genetic gain might be provided using breeder's equation to predict the selection response of a character (Falconer and Mackay 1996; Lynch and Walsh 1998).

The equation can be given as

$$R = (\sigma g \; x \; i \; x \; r)/L$$

Where R is change in character mean in a year

σg = genetic variation present in the population under study

i = selection intensity

r = selection accuracy

L = breeding cycle length

The breeder's equation represents the selection rate of a trait for imparting genetic gain in which length of breeding cycle is an important factor that can be easily manipulated (Cobb *et al.,* 2019). In accordance with this equation, lengthy breeding cycle can be considerably decreased with increased crop generations in a year by using speed breeding which can advance the genetic gain in crop improvement (Chiurugwi *et al*., 2019). In addition the above

equation highlights that genetic gain per unit time can be enhanced by either increasing the heritability with increased phenotyping precision, selection intensity, genetic variability in breeding populations. On the other hand, one of the important critical factor is time requirement for completing a breeding cycle which is the prominent bottleneck in chickpea conventional crop improvement programme.

Climate resilient adaptation

The growing food requirement of human needs, coupled with altering environmental conditions with raising global temperature makes agriculture increasingly challenging (FAO 2019). Chickpea, being a cool rabi season crop, is particularly vulnerable to a wide spectrum of abiotic stresses including drought, frost, salinity, flooding, extreme high and low temperature which has its negative impact in crop growth and productivity (Potters *et al.,* 2007). As the global demand for water in agriculture projected to be nearly doubled by 2050, food production requires climate resilient varieties with enhanced water efficiency is necessitated to sustain food security (Trnka *et al.,* 2019). Compared to conventional breeding approaches, speed breeding offers distinct advantages including capacity to accelerate backcrossing programme, facilitating trait pyramiding and GMO (Genetically modified organisms) pipelines (Shimelis and Laing 2012) thus expediting the development of new varieties for farmers

In addition to abiotic stress conditions, chickpea suffers several biotic constraints too. Among the various biotic stresses, the major biotic stress in chickpea is fusarium wilt (Sharma, 2002). The deployment of resistant varieties developed utilising advanced plant breeding tools remains the most sustainable and eco-friendly strategy for effective biotic and abiotic stress management (Tripati *et al.,* 2022). The speed breeding, an innovative approach may be utilized to accelerate the development of early maturing crop genotypes (Nunavath *et al.* 2020).

Moreover, the crop responds varies with different developmental stages to various stress conditions. The most sensitive phase to abiotic stress is reproductive stage still in chickpea the reduction in seed number is also reported due to exposure of abiotic stress environment at early vegetative stage (Lake and Sadras, 2014). These insights underline the significance of integrating speed breeding technology with stress physiology and crop genomics to design breeding ways and create new cultures that ensure yield stability under emerging global climatic changes.

Prospects

The collaborative effort between the different institutions with modern breeding approaches resulted in reducing three years as compared to conventional breeding methods (Croser *et al.,* 2021). One such innovation is utilization of early generated pods (EGPs) coupled with single seed decent method. This strategy involves use of one single seed from a single pod in a single plant which could aid in rapid turnover of generations. This advancement of generation for accelerated breeding gain in chickpea could progress more efficiently within a given time frame, (Fikre *et al.,* 2021). During the initial breeding stages, the spatial, temporal and resources requirement is high for selecting and advancing the segregating progenies of crosses made between contrasting parental types complimenting each other in order to obtain homozygous lines (Wanga *et al.,* 2020).

Speed breeding protocols designed based on photoperiod manipulation with light and providing light all over the year aids in photosynthesis sustainably (Bhatta *et al.,* 2021). The temperature regime has effect on a range of processes involved in plant growth especially the change from vegetative to flowering stages (Hatfield & Prueger, 2015; McClung et al., 2016). Immature seed germination in chickpea can be attained through regulating the temperature (Samineni et al., 2019). The constraint of high cost involved in speed breeding programmes of developing countries could be combat by use of solar power or battery-operated systems.

The soil moisture content could affect the crop by altering the plant height, flowering, seed set and days to maturity (Anjum et al., 2017; Hussain et al., 2018). Several reports have studied the effect of flooding and drought in triggering the flowering and maturity in various crops. (Shavrukov et al., (2017) Vadez et al., (2012) Agbicodo et al., (2009); Goufo et al., (2017); Zheng et al. (2013) Munamava & Riddoch, (2001) which can be utilized in manipulating speed breeding protocols. Decreasing the frequency of watering during four to six weeks after flowering from every day to two times in a week and ceasing watering at last week before harvest could benefit speed breeding in various crops like chickpea, canola, wheat and barley (Watson et al., 2018).

The spatial and temporal requirement of speed breeding is less compared to conventional breeding methods. High density planting accelerates the transition of vegetative phase to reproductive phase (Warnasooriya & Brutnell, 2014) but variation with genotypes in different crops has been reported by several researchers (Wanga *et al.,* 2020). Carbon dioxide supplementation will speed up the alteration of vegetative stage to that of reproductive stage in some plant species (Jagadish *et al.,* 2016). Dehydration succeeded by chilling made immature seeds to germinate in wheat and barley (Watson *et al*., 2018). This dehydration accompanied by chilling along with manipulation of photoperiod and temperature regime paved way to attain 4-6 generation cycles per year in chickpea, barley, wheat, canola and pea. Reduction in cost could be achieved in establishing speed breeding infrastructure by innovative inventions, usage of local equipment like fitting shipping containers along with solar powered photoperiod and temperature regime manipulation (Chiurugwi *et al.,* 2018).

In other crops, speed breeding was effectively utilised for shortening life cycle and a few examples are quoted here. Cazzola et al., (2020) reported that on application of speed breeding techniques in pea, five generations per year was achieved. Jahne et al., (2017) established five generations per year in soybean; Saxena et al., (2017) achieved four generations per year in pigeonpea and similarly four generations per year was achieved by Watson et al., (2018) in canola and Collard et al., (2017) in rice. A maximum of 7.6 generations per year was achieved in wheat by Zheng et al., (2013).

Constraints

Although speed breeding offers remarkable advantages that could contribute to crop improvement, many constrains hinder the widespread adoption of this technology and its effective utilization. One of the foremost disadvantage is loss of genetic variability as in combination of single seed descent method where only a single seed is advanced in a generation (Saxena *et al.,* 2019). This would forward only a narrow population and may restrain the expression of rare alleles produced in transgressive segregants. It also diminishes recombinant production breaking linkage disequilibrium, thereby limiting the genetic variability available for selection in subsequent cycles of generation.

The speed breeding technique is hampered by the requirement of proficient manpower (Morris *et al.,* 2006). Along with manpower, infrastructure facilities and continuous monetary support is highly essential (Shimelis *et al.,* 2019). In most of the developing countries the institutional support limitation is a major constrain for adoption of speed breeding facilities (Byerlee and Fischer, 2002). The initial screening for trait selection requires specialized tools which also pose major challenge (Ribaut *et al.,* 2010).

Requirement of institutional support limits the implementation of speed breeding and also biotechnological tools (Byerlee and Fischer, 2002). Demand for specialized equipment in trait selection is a major limitation for rapid generation advancement (Ribaut *et al.,* 2010) Manipulation of environmental factors especially soil moisture, photoperiod and temperature regime requires sophistication in speed breeding facilities. Moreover, supplementation of CO_2 needs growth chambers, cylinders, regulators and operational costs along with adherence to health protocols and guidelines for safe handling and usage of CO_2 cylinders.

Continuous supply of electricity and water for maintenance of artificial environment involves high cost as for instance in Queensland during winter temperature regulation cost is more than half of total management cost (O'Connor *et al.,* 2013).

Future thrust

Integration with modern selection tools

Combining the speed breeding strategy with genomic and marker assisted selection could accelerate introgression of desirable traits and development of homozygous cultivars

Development of crop specific protocols

Each crop has unique requirement of photoperiod and other artificial condition. Standardization and optimization of speed breeding technology tailored to chickpea's requirement could enhance positive genotype x environment interactions

Automation and digital phenotyping

Automated imaging with AI based phenotyping and environmental monitoring could help in handling more population for screening

Energy saving growth facilities

Solar power can be utilised for controlled environment systems suitable for adoption of this technology in developing countries

Capacity building programmes

Strengthening of technical expertise by training manpower, establishment of low cost infrastructure and government funding to make the technology accessible to small researchers collaboration would help in accelerating the chickpea breeding for combating climate change.

Multi environment evaluation

The advanced lines bred through speed breeding has to be validated across diverse ecological zones to ensure stability, adaptability and yield performance over locations.

CONCLUSION

Speed breeding had revolutionized and could accelerate the crop improvement programmes by ensuring rapid advancement of generation under controlled artificial conditions. Conventionally chickpea is a single season crop and allows only one generation advancement in a year. The development of homozygous lines could be accelerated which facilitate quick fixation of desirable characters and could be complemented with modern breeding approaches like marker assisted selection (MAS) and genomic selection. Despite these positive outcomes challenges in development of sophisticated infrastructure for artificial condition, uninterrupted power supply, manpower expertise post constrains in utilization of this technology particularly in developing countries. Nevertheless, utilization of speed breeding along with modern tools like marker assisted selection and genomic selection could significantly shorten the breeding cycle and enhancement of genetic gain could also be achieved in chickpea crop improvement programmes.

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