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New challenges in breeding chickpea under changing climate

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Abstract

Climate change is a continuous natural process leading to evolution of diverse flora and fauna. The variability thus created during process of evolution followed by selection of most fit by nature itself forms primary base for crop improvement programs. However, the industrialization led climate change in the present era has been witnessed in form of abrupt rise or drop in temperature, erratic or uneven and untimely rainfall resulting in floods and drought situations. This is a cause of concern as such changes have direct impact on food production. Since most of the pulse crops including chickpea is sensitive to such climate changes, there is need to define likely effects of climate change on chickpea crop and strategies to mitigate its impact on chickpea production and productivity. Among various abiotic and biotic stresses likely to emerge are deficient or high soil moisture, frequent and untimely rains leading to unseasonal flood like situations during winter season, extreme temperatures during different crop growth stages such as frost during vegetative stage, low or high temperature at reproductive stage leading to flower/pod drop and abrupt rise in temperature during vegetative stage leading to initiation of early flowering followed by sudden drop in temperature leading to flower or pod drop; excessive crop growth due to frequent untimely winter rains, higher incidence of root diseases (collar rot and wet root rot) due to high temperature and high soil moisture at early stage of crop growth, increased incidence of foliar diseases (botrytis gray mould, *Ascochyta* blight, *Alternaria* blight, stem rot etc.) due to excessive vegetative growth, and more aggression of weak pathogens causing dry root rot and collar rot are likely to cause huge damage to chickpea crop. Similarly, rise in atmospheric humidity

at the time of flowering and podding stage may lead to higher activities of insect pests like gram pod borer, cut worm etc. Among various strategies to combat these challenges, strategies like screening of germplasm accessions to identify donors possessing traits of economic importance, diseases and insect pest resistance, tolerance to temperature extremities (cold and heat stress), frost, high or low soil moisture stress etc. will be of paramount importance. Careful screening of genetic resources (core or mini-core sets) including wild relatives and primitive landraces will become imperative. The mapping and tagging of gene(s) or quantitative trait loci (QTLs) responsible for imparting resistance/tolerance to abiotic and biotic stresses and yield attributes will be desirable for targeted transfer of the required traits. Further, rapid generation advancement and integration of molecular markers in enhancing efficiency of selection methods will ensure desired improvement in chickpea.

***Key words*:** Breeding, Biotic & abiotic stresses, Chickpea, Climate change

Chickpea is a rich source of energy, protein, minerals, vitamins, fibre, and also contains potentially health beneficial phytochemicals (Wood and Grusak 2007, Jukanti *et al.* 2012) hence, an important component of vegetarian diet in Indian sub-continent, though the seed coat contains many of the antinutritional factors. Chickpea (*Cicer arietinum* L.), one of the most important winter season legumes of the world, is grown in India on about 8.5 to 9.5 m ha area under varying agro-ecological conditions producing 8-9 m t of the grain. In India, during 2013-14, when pulses production was highest (19.27 m t), chickpea also attained ever highest production (9.88 m t) contributing more than 51% to the national pulse basket and registering more than 1000 kg/ha productivity (Singh 2014). The intrinsic characteristic that this crop can be grown well under harsh environmental condition with minimum input has restricted policy makers and scientists towards making investments in terms of research and development efforts until last 2 decades. Since, chickpea share in pulses area is huge; it has to contribute significantly to ensure nutritional security and attaining self reliance in pulses production in India. As chickpea is a winter season crop, the expected impact of climate change in terms of temperature extremities, excessive rains or high soil moisture, foggy days, poor quality of sunlight, abrupt rise or drop in temperature during crop growth period etc. will be more. The emergence of new diseases and pests are likely to impact production and productively of chickpea. The chickpea is grown in almost all parts of the country covering Tamil Nadu in south to Jammu & Kashmir in north; Assam in east and Gujarat in west, therefore, the impact of climate change will affect chickpea crop in both direction, positive and negative. Therefore, systematic studies involving simulation and crop modeling need to be carried out so that present level of production can be sustained and further improved.

Emerging challenges

Climate change is a continuous natural process that leads to evolution. However, in present context the climate change has been observed in form of unprecedented rain fall patterns (less number of rainy days, more incidence of drought and floods etc.), abrupt rise or drop in temperature and humidity, more number of foggy days leading to poor quality of sunlight during crop growth etc. Climate change led emergence of newer diseases (*Alternaria* blight, stem rot, collar rot, rust etc.) and incidence of known diseases (wilt, dry root rot, ascochyta blight, botrytis gray mold, etc) is likely to increase besides increased activities of the insect pests (gram pod borer, cut worm etc.) as high humidity or fog is becoming a regular phenomenon of climate change in general throughout area under chickpea cultivation in India and more specifically in northern India. Due to poor quality of sunlight (due to fog) the availability of micro-nutrients in soil or application of nutrients to the crop may respond inadequately. Under harsh environmental conditions, utilization of nutrients and nodulation may also be affected. However, with the rise in temperature during mid-December to January is likely to help crop growth in northern India.

Challenges vis-à-vis strategies

Large number of biotic and abiotic stresses limits realization of full yield potential of chickpea crop at farmers' fields. To minimize losses due to these stresses, enhance yield levels and to promote its cultivation, several strategies including genetic options were suggested and adopted in past (Nadarajan and Chaturvedi 2010; Kaur *et al.* 2013; Chaturvedi *et al.* 2014) and chickpea production could be raised to the level of 9.88 m t during 2013-14. The emerging challenges and strategies to enhance production and yields are being presented in following paras:

(i) *Diseases and insect pests*

As many as 47 diseases (Nene and Reddy 1987) and 54 insect pests (Reed *et al.* 1987) are known to cause crop loss. Among these, Fusarium wilt (*Fusarium oxysporum* f. sp. *ciceri*), Ascochyta blight (*Ascochyta rabiei*) and Botrytis grey mould (*Botrytis cinerea*) are the major diseases and gram pod borer (*Helicoverpa armigera* Hubner) is the major insect that plays havoc (Chaturvedi *et al.* 2013) in all major chickpea growing areas of the country (Table 1). Exploitation of host plant resistance to minimize losses likely to be caused by the incidence of diseases is the most feasible, ease in adoption and economically viable option to manage diseases and insect pests. Systematic screening of germplasm accessions (wild *Cicer* and primitive land races) to identify donors possessing resistance to important prevailing diseases and emerging ones is of utmost importance to insulate future varieties against emerging diseases. The race specific donors (if races are known to exist) for diseases like collar rot, botrytis grey mould, wet root rot, stem rot, alternaria blight and ascochyta blight need to be identified in the better agronomic backgrounds; and multiple diseases resistant varieties need to be developed so that yield potential of varieties can be harvested at farmers' fields. In view of the climate change, higher incidence of foliar diseases like botrytis gray mould (*Botrytis* *cinerea*) in sub-humid region like *Terai* belt of India, *Ascochyta* blight (*Ascochyta rabiei*) in wet and cold areas like north-west plains, *Alternaria* blight in late sown crop in eastern India etc. may increase due to excessive vegetative growth. Similarly, higher order of aggression of weak pathogens causing dry root rot (*Rhizoctonia bataticola*), collar rot (*Sclerotinia rolfsii*) and stem rot (*Sclerotium sclerotiorum*) etc. can be seen that may lead to more crop losses. With the increasing policy support, efforts are being made for diversification of rice-wheat cropping system or popularization of chickpea in late sown conditions after harvest of paddy in north-east plains of Bihar, Jharkhand, Odisha and Assam. Such late sown crop would attract *Alternaria* causing alternaria blight in chickpea and can emerge as a major disease limiting chickpea productivity in northern plains with the spread of its cultivation. On the other hand, with the increase in humidity, diseases like rust and BGM may affect crop in southern India where mild cold exists. Therefore, efforts should be made for identification of sources of resistance against these diseases so that chickpea cultivation can be sustained for long term. Further, it is important to screen accessions of wild *Cicer* and primitive landraces to identify sources of tolerance, if not resistance. For example, there were no source of resistance known against BGM but recently, derivative of interspecific cross (*C. arietinum* x *C. pinnatifidum*) has shown high level of resistance to botrytis grey mould (Kaur *et al.* 2013) and these derivatives can be utilized to exploit host plant resistance. Considering the importance of wild relatives, sincere efforts led in collection and maintenance resulted in enhanced proportion of wild relatives in gene bank holdings during 1983 (Plucknett *et al.* 1987) to 2004 (http://singer.grinfo.net/). Hajjar and Hodgkin (2007) reviewed and summarized exploitation of wild relatives for improvement of major crop species for the last 20 years and pinpointed number of traits transferred in desirable backgrounds.

It is known fact that there is limited level of tolerance available in chickpea germplasm against gram pod borer (*Helicoverpa armigera* Hubner) and other insect pests. The potential rests with the development of transgenic against gram pod borer. Several reviews are available indicating availability of donor parents possessing resistance/tolerance to many diseases and achievements made through utilization of

Table 1. Major diseases and insects in different states in India

States	Diseases	Insect pests
Eastern Uttar Pradesh, Bihar, Jharkhand, West Bengal, Assam	*Fusarium* wilt, dry and wet root rot, *Botrytis* grey mould Emerging diseases: Collar rot, rust, alternaria, stemphylium blight	Gram pod borer, cut worm
Punjab, Haryana, Himachal Pradesh, Jammu & Kashmir, Uttaranchal, North Rajasthan and western Uttar Pradesh	*Fusarium* wilt, dry and wet root rot, *Ascochyta* blight, *Botrytis* grey mould Emerging diseases: Collar rot, stem rot, stunt and rust	Gram pod borer
Gujarat, Maharashtra, Madhya Pradesh, Chhattisgarh, part of Rajasthan	*Fusarium* wilt and dry root rots, stunt virus Emerging diseases: Collar rot and wet root rot	Gram pod borer, cut worm
Andhra Pradesh, Karnataka, Tamil Nadu	*Fusarium* wilt and dry root rot, stunt virus Emerging diseases: Collar rot and wet root rot	Gram pod borer

Source: *revised after* Chaturvedi *et al.* (2013)

some of these donors in development of high yielding varieties (Gaur *et al.* 2007; Gaur *et al.* 2012a, Chaturvedi *et al.* 2003, Chaturvedi *et al.* 2013).

Further, the mechanism of resistance/tolerance for diseases and insect pests should be worked out using diverse material so that new gene(s)/QTLs responsible for imparting such resistances may be transferred systematically to desirable agronomic background. The power of molecular markers needs exploitation as it can help in enhancing efficiency of selection for pyramiding of genes conferring resistance to different biotic stresses during varietal development process.

(ii) ***Weeds:*** Seasonal weed pose serious threat to chickpea cultivation in many parts of the country wherever high soil moisture prevails at the time of crop growth stage. With the rising labour cost and non-availability of farm labours, it has become inevitable to manage weeds with the spray of post emergence weedicides/herbicides. Chickpea crop is very sensitive to most of the herbicides, therefore, systematic screening of herbicide tolerance in germplasm including wild ones has become of paramount importance. The alternate approach can be to develop herbicide tolerant transgenic chickpea cultivars, which requires favourable policies and changed mind in most of the countries including India. Indian Institute of Pulses Research (IIPR), International Crops Research Centre for the Semi Arid Tropics (ICRISAT) and several other centres are working together under a dedicated research project to develop post emergence herbicide tolerant chickpea varieties and have already identified herbicide tolerant germplasm lines (Gaur *et al.* 2013; Chaturvedi *et al.* 2014). These efforts are likely to generate scientific information to minimize losses due to weeds in chickpea.

(iii) ***Abiotic stresses***

Development of climate smart crop varieties exploiting *per se* tolerance to abiotic stresses like soil moisture stress, terminal drought, cold, frost and high temperature stress and salinity/alkalinity etc. is of paramount importance. Efforts should be made to identify race specific donors and insect pest resistance, tolerance to temperature extremities (cold and heat stress), frost, high or low soil moisture stress etc. will be of paramount importance. Careful screening of genetic resources (core or mini-core sets) including wild relatives and primitive landraces has become imperative for identification of high temperature (Krishnamurthy *et al.* 2011) and cold tolerant (Chaturvedi *et al.* 2009) genotypes for development of heat and cold tolerant varieties of chickpea. The development of genomic resources for systematic and targeted transfer of useful gene(s) and quantitative trait loci (QTLs) to insulate present day varieties against major abiotic stresses (Jha *et al.* 2013) is the need of the day. Among other strategies, resource conservation technologies are likely to play an important role. Accordingly, restructuring of plant type has been suggested (Chaturvedi *et al.* 2013). For the purpose of development of climate smart varieties, large genetic variations for heat tolerance (Basu *et al.* 2009; Krishnamurthy *et al.* 2011; Gaur *et al.* 2014a), chilling stress response (Jens *et* *al.* 2012) and cold tolerance (Chaturvedi *et al.* 2009; Sandhu *et al.* 2005) have been reported besides utilization strategies to develop tolerant varieties to improve chickpea yields under harsh environmental conditions (Jha *et al.* 2014). Researchers have dissected drought and heat tolerance through genome-wide and candidate gene-based association mapping approaches and outlined genomic assisted breeding for drought tolerance (Gaur *et al.* 2012a, 2012b; Thudi *et al.* 2014a and 2014b; Jha *et al.* 2014). Still lot of efforts are required to develop high yielding varieties with *per se* tolerance to abiotic stresses integrating molecular approaches.

(iv) Restructuring plant type

To enhance photosynthetic and input use efficiency, reduction in cost of cultivation and minimizing foliar diseases and make varieties amenable to intercropping, mechanical harvesting and ease in intercultural operations, there is urgent need to restructure existing bushy/semi-spreading plant types. Several mutants with desirable traits like cymose inflorescence having more than three flowers per node (Gaur and Gour 2002; Srinivasan *et al.* 2009), brachytic growth habit (Gaur *et al.* 2008) and determinate growth habit (Hegde 2011) and mutant with short internode (E100ym) and erect growth (Chaturvedi *et al.* 2010) offer ample scope for restructuring chickpea varieties for their suitability to mechanized harvesting (Sandhu *et al.* 2010; Gaur *et al.* 2012a).

(v) Phosphorus acquisition efficiency

Phosphorus deficiency is wide spread among soils of chickpea growing areas in India. Receding soil moisture at later stage of crop is known to limit availability of nutrients to the crop plants. Low phosphorus availability in soil restricts proper plant growth affecting nodulation and reducing contribution from biological nitrogen fixation in pulses, thereby decreasing grain yields of pulse crops. The nutrient use efficiency further constraints when soil moisture (high or low) stress prevails during crop season. Chickpea, an important pulse crop is grown on about 8-9 million hectare area with seldom use of adequate dose of phosphorus fertilizers. Development of high yielding varieties with better P-acquisition efficiency and ability to grow well on P-deficient soils, should be an important objective for enhancing grain yield of chickpea in years to come. Cultivation of P-acquisition efficient varieties in low-input production systems will not only reduce the production costs associated with 'P' fertilizer applications but also contribute towards enhanced 'P' use efficiency. ICAR-Indian Institute of Pulses Research, Kanpur (India) initiated research in winter season (Rabi) 2011-12 in sandy loam soils of New Research Farm to identify chickpea genotypes with better 'P' acquisition efficiency under low Olson's P (6.2 μg/g soil) condition of soil. Accordingly, a study was initiated to evaluate effect of soil phosphorus deficiency on chickpea grain yield and grain protein contents in seven selected elite chickpea breeding lines (IPC2006-84, IPC2010-152, IPC2005-44, IPC2008-34, IPC 2008-92, IPC 2006-14,and IPC 2011-01) along with two check varieties viz., BG 256 and JG 16. These 9 genotypes were grown under field conditions during *Rabi* 2013-14 under low and high soil fertility conditions having low (6.2 µg/g soil) and high (25 µg/g soil) soil phosphorus availability (Olson's P) at Indian Institute of Pulses Research, Kanpur (Mohan Singh: personal communication). The 'P' deficiency resulted in decreased grain yields ranging from 14 to 27% with the exception of almost no reduction in IPC 2008-92. Further, grain yield of check varieties BG 256 and JG16 were decreased from 1515.0 and 1016 kg ha^{-1} to 1181 and 862 kg ha^{-1}, a reduction of 22 and 15 per cent, respectively due to low 'P' status. Under low P conditions, IPC 2006-14 (1472 kg ha^{-1}) and IPC 2008-92 (1228 kg ha^{-1}) gave higher yields in comparison of JG 16 (862 kg ha^{-1}). In other breeding lines, reduction in grain yields was observed to the tune of 25-27 %. Similarly, drastic reduction in grain protein content was also observed in some of the genotypes under 'P' deficiency condition. Chickpea genotypes *viz.*, JG 16, IPC 2006-14, IPC 2010-152 and IPC 2011-01 showed marginal reduction (<1%) whereas BG 256 (32%) and IPC 2005-44 (20%) exhibited drastic reduction in grain protein content. Protein yield, a product of grain yield and grain protein content decreased from 31 to 47 per cent in three genotypes *viz.* IPC 2005-44, IPC 2008-34 and BG 256 indicating that P deficiency in soil not only decreased grain yield but also adversely influenced upon seed quality such as protein content. Genotype like IPC 2008-92 showed minimum reduction in both grain yield as well as protein content in comparison to the check BG 256. It is concluded that in view of the prevalent P-deficiency in soils of pulse growing areas and limited application of 'P' fertilizers in pulses, it would be more advantageous to develop varieties having potential to efficiently utilize soil 'P' from both soil as well as externally applied phosphorus fertilizers with minimum reduction in both grain yield as well as seed protein content. This approach should be adopted in future research and development programs for augmenting protein yields per unit area through pulses.

(vi) Molecular approaches for transfer of useful traits

The mapping and tagging of gene(s) or quantitative trait loci (QTLs) responsible for imparting resistance/tolerance to abiotic and biotic stresses and yield attributes will be desirable for targeted transfer of the traits. The development of large number of simple sequence repeat (SSR) markers opened doors for extensive use of molecular markers in chickpea breeding. The multi-allelic and co-dominant nature of SSR markers made them ideal markers for genomic studies and for use in practical chickpea breeding. The SSR markers have been developed from sequence information obtained from various sources, including genomic libraries (Winter *et al.* 1999; Nayak *et al.* 2010), bacterial artificial chromosome (BAC) libraries and BAC-end sequences (Thudi *et al.* 2011), tentative unique sequences (TUS) (Hiremath *et al.* 2011) and expressed sequence tags (ESTs) (Varshney *et al.* 2009; Gujaria *et al.* 2011; Hiremath *et al.* 2011). Over 2000 SSR markers are now available for chickpea. The recently published draft genome sequence of chickpea identified over 48000 SSRs suitable for PCR primer design for use as genetic markers (Varshney *et al.* 2013a). In chickpea, using diversity arrays technology, 15360

DArT markers were generated from 94 diverse genotypes and 5397 of these were found polymorphic (Thudi *et al.* 2011). Later, single nucleotide polymorphism (SNP) markers have become the preferred choice of markers because of their abundance, co-dominant nature, and amenability to high-throughput analysis. Several thousand SNPs have been identified from transcriptome analysis in chickpea (Varsheny *et al.* 2009b; Gujaria *et al.* 2011; Hiremath *et al.* 2011). Using information generated through draft genome sequence of chickpea 76084 SNPs were identified in 15526 genes. Of these, 27117 SNPs were identified within the cultivated species and 54178 SNPs between the cultivated species and its progenitor *Cicer reticulatum*. With the availability of draft genome sequence (Varshney *et al.* 2013a) ample scope exists to develop large number of genomic resources, robust molecular markers linked with useful gene(s) and their systematic transfer to develop climate smart and high yielding varieties with stable performance. Integration of molecular markers in enhancing efficiency of selection methods will ensure desired improvement at rapid rate in chickpea.

(vii) Rapid generation advancement

Efforts should be made for rapid generation advancement so that duration required for the development of varieties can be minimized. Considering the importance of rapid generation advancement to hasten breeding cycle, ICAR-Indian Institute of Pulses Research has established off-season nursery centre at Dharwad (Karnataka). This centre is taking care for rapid generation turnover requirements of various centres involved in chickpea breeding.

Conventional breeding has led in development of more than 200 high yielding varieties insulated well against major biotic and abiotic stresses in past. This led in production and productivity gains which is evident from the increased production as share of chickpea production (9.88 m t) has gone up during last one decade and during 2013-14 chickpea's share in total pulses production (19.27 m t) in India was more than 51%. Further, the productivity also crossed 1000 kg/ha. However, to improve the complex traits for which phenotyping/selection from segregating generations is difficult and to hasten breeding cycle deployment of molecular markers linked with targeted genes/QTLs is required. Marker-assisted breeding are known to improve precision and efficiency of breeding programs during selection of desirable segregants. Recent advances in development of large number of molecular markers linked with useful genes/QTLs controlling traits of breeders' interest have encouraged applications of marker-assisted backcrossing (MABC) in chickpea improvement. A "QTL-hotspot" containing QTLs for several root and drought tolerance traits was transferred from the drought tolerant line ICC4958 to a popular *desi* chickpea variety JG 11 through marker assisted back crossing scheme (Varshney *et al.* 2013b). Varshney *et al.* (2013b) further reviewed status of genomic resources available for chickpea improvement and suggested ways to go for marker assisted breeding for development of future varieties in chickpea. Further, Gaur *et al.* (2013b) reported identification of improved lines with significantly higher yield than JG11 through multi-location evaluations of introgression lines in India, Ethiopia and Kenya. The results indicate the worth of the introgression of identified "QTL-hotspot" in chickpea improvement. Marker-assisted recurrent selection (MARS) has also been initiated in chickpea for improvement of yield, particularly under moisture stress conditions. Two good-by-good crosses (JG 11 × ICCV 04112 and JG 130 × ICCV 05107) are being used at ICRISAT to implement MARS (Gaur *et al.* 2014b). QTLs were identified specific to these crosses by genotyping in F_3 and phenotyping of F3:5 progenies. In addition to Marker-assisted recurrent selection, genome wide selection (GWS) or genomic selections (GS) are being considered as potential approaches for improving complex traits governed by many genes/QTL with the advantage that in GWS/GS, both phenotyping and genotyping data are used to predict genomic estimated breeding values (GEBVs) of progenies and superior progenies are selected based on GEBVs, however, GWS is yet to be implemented for improving chickpea. Considering the potential of non-conventional tools of selection from segregating populations, integrated approach involving conventional and molecular marker based selections should be adopted to ensure rapid genetic and productivity gains through development of high yielding cultivars having useful traits combinations.

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