Research Article

Genetic enhancement for grain yield in chickpea – accomplishments and resetting research agenda

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Abstract
Chickpea (*Cicer arietinum* L.), commonly known as 'gram' is one of the major pulse crops of India covering 7.97 m ha area producing 7.06 m t of the grains and registering all time productivity of 885 kg/ha during 2008-09. This has become possible due to development and popularization of high yielding varieties insulated well against various biotic and abiotic stresses for various parts of the country. Some of these high yielding are GNG 158, Vijay, DCP 92-3, Rajas, Digvijay, KWR 108, H 82-2, RSG 888, JG 315, Vijay, JG 16, ICCV 10, JG 11, KGD 1168, GNG 469, Pusa 372, KPG 59, ICCV 2, Shubhra (IPCK 2002-29), BGD 128, Pusa Chamatkar (BG 1053), JGK 1 and Pusa kabuli 1003 which have stable resistance against wilt. Similarly PBG 5, GNG 469, PBG 1, Pusa 413, Pusa 408, Pusa 417 and Himachal chana 1 have resistance against ascochyta blight besides high yield potential. Little efforts have been made in vast variability present among germplasm accessions, which are available with several International and National Institutes. Inter-mating between accessions/elite lines of same origin or inter-varietal crosses led varieties development has resulted in narrow genetic base of existing cultivars. Little efforts have been made in exploitation of wild *Cicer* and exotic collections also. Concerted and systematic efforts are required to harness the potential of this vast variability. In view of the changing climatic and global scenario there is urgent need to reorient breeding programme so that desired level of genetic enhancement can be achieved. Genetic options for mitigating terminal soil moisture stress and high temperature, both at reproductive and vegetative stage, development of genotypes with high nutrient efficiency need care in breeding programmes. Besides, biotic and abiotic stresses now trade has become more important. Ttherefore development varieties possessing consumers' preferred traits like seed size in kabuli and milling quality in desi chickpea need special attention. With the advent of powerful non-conventional approaches for transferring genes from wild sources and even other genera, it has become possible to develop resistant cultivars for dreaded insect pest like gram pod borer, *Helicoverpa armigera* Hubner. Hence potential of biotechnological tools must be exploited. The potential of molecular marker technology in transferring of targeted traits with utmost efficiency or QTLs/ targeted genes has been discussed along with efforts on mapping and tagging of genes conferring resistance/tolerance to major diseases and abiotic stresses. The present paper deals with the accomplishments' made and the research agenda for genetic enhancement of grain yield and production of chickpea in India in near future.

Key words: Chickpea, gene pools, genetic diversity, plant types, resistance

Introduction

Chickpea (*Cicer arietinum* L.) is known by various names *viz*., Bengal gram, Gram, Chhola and Hommes etc. in different parts of the world. In India, chickpea ranks first in area and production covering 7.97 m ha area and producing 7.06 m t of the grains. Its contribution in total pulses production is more than 48.5% (2008-09) registering all time high productivity (885 kg/ha). The production levels are expected to go further (7.46 m t : second estimates of Department of Agriculture and Cooperation, Government of India) during 2009-10. In India, Madhya Pradesh, Rajasthan, Uttar Pradesh, Maharashtra, Andhra Pradesh, Gujarat, Karnataka, Bihar, Jharkhand and Chhattisgarh are the major chickpea producing states sharing over 90 % area. The area under this crop gone down drastically in north Indian states whereas it has gone up in central and south Indian states during last decade. The variation in productivity among chickpea growing states has also been observed suggesting scope for productivity enhancement through development of suitable high yielding varieties and matching crop production and protection technologies. The realized productivity and production of chickpea can be far more than what is being harvested today, provided the crop is protected from the vagaries of various biotic and abiotic stresses.

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Revisiting chickpea research priorities? Why

Production statistics over decades clearly indicate that the present day varieties have provided much needed stability in production and productivity of chickpea in India. However, the productivity could not be enhanced to the desired level and production figures could not maintain pace with rising demand of chickpea for increasing population. There is little scope for area expansion therefore; only viable option is to develop high yielding varieties with better productivity. Due emphasis has been placed in National Food Security Mission (NFSM) to increase seed replacement rate (SRR) from present level of 8-10% to 25% for pulse crops. Since, chickpea has lion share in total pulses acreage (almost 36%), it has to contribute significantly. In context of globalization of agriculture and climate change which can be realized as abrupt rise or drop in temperature during crop season, there is urgent need to revisit the chickpea research priorities so that desired nutritional security can be provided to large agrarian population of the country. Govt. of India is fully aware of its responsibility of ensuring food security to people of the country, thus adopted a resolution in 53rd meeting of The National Development Council (NDC), held on 29th May 2007 to launch a Food Security Mission to increase the production of rice, wheat and pulses. A scheme "**National Food Security Mission (NFSM)**" sponsored by Govt. of India has been launched from 2007-08 to increase the production of rice by 10 million tons, wheat by 8 million tons and pulses by 2 million tons by the end of the XI Plan (2011-12) with the financial out lay of Rs. 25,000/- crores.

Production constraints:

In India, chickpea is normally cultivated in rainfed areas (>70% area), which are characterized by poor soil fertility and low moisture retention capacity as a result crop often faces moisture stress at various growth stages. The rainfall is not only low but also highly erratic and uncertain in rainfed areas. A number of biotic (Table 1: diseases and insect pests) and abiotic stresses limit the chickpea production and productivity in India. Among various diseases, *Fusarium* wilt, *Ascochyta* blight, wet and dry root rot, stem and collar rot and *Botrytis* gray mould are prominent. Similarly, gram pod borer (*Helicoverpa armigera*), cutworm (*Agrotis ipsilon*), semilooper (*Autographa nigrisigna*) and bruchid (*Callosobruchus chinensis*) cause huge losses in chickpea production at various stages of the crop growth and storage. The root knot nematodes are also posing serious threat to chickpea cultivation under sandy loam/light soils of states like Rajasthan and Gujarat. Among various abiotic stresses soil salinity and alkalinity, terminal moisture stress, low and high temperature, foggy weather and lodging under high input conditions are the major problems in achieving higher yield.

Non- availability of input responsive varieties remains a major bottleneck in achieving higher productivity levels even in high productive environment of North India. Crop lodging remains a major constraint as application of fertilizers and other nutrients along with irrigation cause excessive vegetative growth. Among various breeding constraints limited or very poor exploitation of wild *Cicer* sps., seasonal fluctuation in yield due to biotic and abiotic stresses and negative associations among major yield components are major ones.

Accomplishments

Among pulses, chickpea has the longest history of research in India. It started as early as in 1905 when Imperial Agricultural Research Institute was established at Pusa (Bihar). Many high yielding, diseases resistant varieties were developed, which led to the stability in chickpea production with about 2.02% annual growth rate in productivity. As on today, more than 140 varieties for various states and agro-ecological conditions have been recommended for cultivation through national or state programme. More than 100 high yielding varieties have been developed through collaborative efforts under ambit of All India Coordinated Research Project on Chickpea by various State Agricultural Universities (SAUs), Indian Institute of Pulses Research (IIPR) and Indian Agricultural Research Institute (IARI) during last 20-25 years. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has contributed significantly in variety development by way of sharing germplasm accessions, donors and advance breeding/elite lines. Among the prominent varieties GNG 158, Vijay, DCP 92-3, Vishal, Rajas, Digvijay, KWR 108, H 82-2, RSG 963, RSG 888, GPF 2, JG 315, Vijay, JG 16, JG 74, ICCV 10, JG 11, KGD 1168, GNG 469, GCP 105, GNG 663, Pusa 372, Shubhra (IPCK 2002-29), BGD 128, Pragati, Pusa Chamatkar, JKG 1 and Pusa kabuli 1003 have stable resistance against wilt. Whereas PBG 5, GNG 469, PBG 1, Pusa 413, Pusa 408 and Himachal chana 1 have resistance against ascochyta blight. A number of high yielding medium/large seeded kabuli chickpea varieties have also been released for cultivation. Some of these are Shubhra, Jawahar Gram Kabuli 1 (JGK 1), KAK 2, Pusa Chamatkar (BG 1053), Vihar, BGD 128, Phule G 95311 and Haryana Kabuli chana 1. More recently, extra large seeded (>50 g/100 seed weight) kabuli chickpea varieties Phule G 0517 and PKV 4- have been developed. These varieties will help in generating more income per unit area, thus encourage farmers to grow chickpea in irrigated areas. Similarly, chickpea varieties (Pusa 547, Rajas, RSG 963, KPG 59, Pusa 372, Pant G 186 and PBG 5) suitable for late sown conditions of Punjab, Haryana, Uttar Pradesh, Bihar, parts of Chhatisgarh and Jharkhand have been developed. In areas, where due to high soil moisture, frequent winter rains or high water table and high fertility chickpea crop attain more vegetative growth resulting in lodging and subsequent yield loss, the wilt resistant chickpea variety DCP 92-3 can be grown successfully. Similarly, chickpea variety Karnal chana 1 (CSG 8962) can be grown successfully under mild salinity conditions of north-west plains. The variety RSG 888 has been recommended for cultivation in moisture stress conditions (drought prone areas) of Rajasthan, Punjab and Haryana. Matching crop production and protection technologies have also been developed to boost chickpea production. Efforts have been initiated for the development of transgenic against *Helicoverpa armigera* Hub. Similarly, massive programme for exploitation of molecular markers has been initiated at various State Agriculture Universities and Institutes.

Resetting research agenda

There can be several viable options to realize genetic yield potential of chickpea. Breeding programmes need to be reoriented for development of high yielding varieties responsive to high inputs. The enhancement of yield potential under different cropping systems should be the integral part of the varietal development programmes. Similarly, development of multi-adversities resistance varieties against major biotic and abiotic stresses should get due attention to realize the potential yield of modern varieties. Following can be the major research approaches to enhance yield potential and productivity of chickpea.

a) Germplasm enhancement

So far very less amount of variability has been exploited for development of HYV in chickpea. Most of the varieties have been developed through selection or inter-varietal crosses. There is urgent need to broaden the genetic base of existing cultivars. The systematic evaluation of germplasm and their documentation is of paramount importance. The exploitation of vast diversity should be adopted in Mission mode approach to achieve the goal. This has been already initiated under NBPGR-IIPR-SAU network project on germplasm evaluation and characterization under which more than 2500 germplasm accessions have been evaluated. Three centers, namely, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India (19187 accessions), International Center for Agricultural Research in the Dry Areas (ICARDA), Syria (12647 accessions), and National Bureau of Plant Genetic Resources (NBPGR), India (14566 accessions) hold the major chickpea collections. Plant genetic resources are the most valuable among all the natural resources. To conserve vast plant biodiversity, large-scale efforts were made to collect before it is lost forever. Most of what is collectable has been collected (Jain, 2004). Sets of selected chickpea germplasm were evaluated for important agronomic characters at different locations in India and several other countries and at or near the place of origin and suitable season. Germplasm characterization data was summarized; catalogs were prepared (Pundir *et al*., 1988; Remanandan et al., 1988, Singh and Kumar, 2004) and distributed to researchers.

b) Breeding for suitable plant type:

Development of suitable plant types for various cropping systems and sequences are of great importance as chickpea is being cultivated as mixed, sole or intercrop in various agro-ecological situations and zones. The efforts are needed to develop efficient plant types through manipulation of morpho-physiological traits and development of determinate type of plant specifically for high input conditions. We, at Indian Institute of Pulses Research have proposed suitable plant types for various agro-ecological situations (Table 2) which have been validated partly for irrigated and rainfed conditions:

c) Wide hybridization

For diversification and broadening the genetic base of resistance, introgression of until unexplored genes from the wild relatives needs to be persuaded to minimize the risk of epidemics. Wild *Cicer* species are rich reservoir of resistance/tolerance genes against various biotic and abiotic stresses (Table 3). *Cicer judaicum* is a source of resistance genes to *Ascochyta* blight, *Fusarium* wilt and *Botrytis* gray mould (van der Maesen and Pundir 1984). Verma et al. (1990) reported successful crosses between *C. arietinum* and *C. judaicum*. They further characterize this cross for various traits including disease resistance. Singh *et al.* (1982) reported *C. pinnatifidum* to be resistant to Botrytis gray mould. Sources of resistance to cyst nematode are available in *C. bijugum*, *C. pinnatifidum* and *C. reticulatum* (Greco and Di Vito 1993). High level of cold tolerance is present in *C. reticulatum* and *C. bijugum* (Singh *et al.* 1995). Some accessions of the wild *Cicer* sps. have shown resistance to multiple stresses. For example, ILWC 7-1 (*C. bijugum)* is resistant to Ascochyta blight, Fusarium wilt, leaf miner, cyst nematode, and cold. Similarly, ILWC 33/S-4 (*Cicer pinnatifidum)* is resistant to *Ascochyta* blight, *Fusarium* wilt, seed beetle and cyst nematode. Conventional crossing has been successful in producing inter-specific hybrids between *C. arietinum* and *C. reticulatum*. Recent success in inter-specific hybrid between *C. arietinum* and *C. echinospermum* and availability of new biotechnology tools for circumventing crossing barriers have further brightened the prospects of transferring useful traits from tertiary gene pool. Introgression of resistance genes for cyst nematode from *C. reticulatum* (Di Vito *et al.* 1996) and cold temperature from *C. reticulatum* and *C. echinospermum* (ICARDA, 1996; Malhotra et al., 2003) are examples of successful utilization of wild species for combating biotic and abiotic stresses.

Interspecific hybrid between *C. arietinum x C. echinospermum* has been successfully made by Knights (2003) also to incorporate resistance to *Ascochyta* blight in cultivated types. Recently, interspecific crosses (*C. arietinum* cv ICC 87322 x *C. reticulatum and* crosses (*C. arietinum* cv K 850m x *C. reticulatum)* have been made at Pantnagar (D.P. Singh, Pers. Communication). However, at PAU, Ludhiana, JNKVV Jabalpur and IARI many interspecific crosses were made in past. Successful transfer of many desirable traits has been achieved in many cases in different pulses. However, much of the literature reports identification and production of interspecific hybrids but rarely on the actual release of new cultivars and its use by farmers. A wide gap exists between making initial hybrids and releasing cultivars with good agronomic performance and high yield (Singh *et al.,* 2003). The main reason behind failure in achieving the desired success was that the resulting breeding lines from such crosses were directly evaluated for yield in AICRP trials and not for the other specific traits like yield attributes and resistance to various diseases, insect pests and abiotic stresses. There is urgent need to further utilize the derivatives of interspecific crosses in hybridization for the development of suitable cultivars. Indian Institute of Pulses Research, Kanpur, is maintaining different accessions of *Cicer reticulatum* and *C. judaicum* from last 10 years. These were utilized for the development of pre-breeding line. A pre-breeding line IPC 71 (*C. arietinum x C. judaicum*) has been developed and used as donor under National crossing Programme. This line possesses high number of primary branches per plant, more pods per plant and green seeds. Singh et al. (1999) have reported successful interspecific hybrids between *Cicer arietinum* and *C. reticulatum* at IIPR, Kanpur. Recently, large number of interspecific crosses involving *C. reticulatum* has been made and single plant selections have been made at IIPR (IIPR

Annual Report 2009-2010). Pre- and post fertilization barriers have also been reported and their strategies to overcome these were suggested. Embryo rescue technique has been found quite useful in achieving success in making interspecific hybrids using secondary gene pool species. Hybrids between *C. arietinum* and *C. reticulatum* showed normal fertility. However, many undesirable traits are also transferred from *C. reticulatum*. To overcome this problem, use of *C. reticulatum* as male parent is suggested.

d) Multiple disease and pest resistance:

Similar to other crops, exploitation of host plant resistance for development of disease/pest resistant varieties remains most viable and economically feasible option for the management of biotic stresses in chickpea also. It has helped greatly in minimizing yield losses at farmers' field. Since the incidence of diseases and insect pests is often not predictable, varieties having multiple resistances to diseases and pests provide greater insurance against crop failures. In past we have released number of high yielding varieties possessing resistance to more than one disease or adversity (JG 11, JG 16, GNG 1581, H 82-2, DCP 92-2, Vijay, Digvijay, JG 315, RAG 888, GPF 2, BG 391, Pusa Chamatkar, JGK 1, GCP 105, KWR 108, Pant G 186 etc.) has provided desired stability to chickpea productivity.

e) Development of short duration varieties

To bring additional area under chickpea, there is urgent need to develop short duration varieties (like ICCV 2, JG 11, Pant G 186, JG 14 etc.) suitable for late sown conditions of northern India. Such varieties should possess early growth vigour, tolerance to low temperature at vegetative stage to ensure sufficient biomass and capability of formation of pod and seed before rise in temperature to realize high yield per unit time. Similarly in south and central India, early maturity will help in reducing the losses likely to be caused by pod borer, high temperature and end of season drought. In this direction efforts have been diverted recently and short duration varieties possessing high temperature tolerance are being developed.

f) Exploitation of molecular marker technology

The molecular markers offer great opportunity for facilitating and improving precision of selection for resistance in segregating generations. The marker-assisted selection (MAS) will help in pyramiding of genes from different sources. Mapping populations are being developed for drought; heat and fusarium wilt which will help in mapping and tagging of genes responsible for resistance/tolerance against abiotic and biotic stresses.

g) Transgenic approach

The transgenic technology offers opportunity of introducing genes in a crop from any source including other organisms. The concerted efforts should be made to develop transgenic chickpea against gram pod borer. In recent years efforts have been initiated for the development of transgenic against *Helicoverpa armigera* Hub. using Cry 1Aabc and Cry 1 Ac genes at various Institutions including Indian Institute of Pulses Research, Kanpur and at present T_3 seeds are available with IIPR.

h) Development of race specific donors and phenotyping techniques against biotic and abiotic stresses

Physiological races in pathogens like *Fusarium oxysporum* f.sp. *ciceri* and *Ascochyta rabiei* are known to exist. Molecular characterization will help in understanding of the behaviour of the pathogens, which in turn help in making appropriate strategies to identify race specific donors and their exploitation for the development of disease resistant varieties. To exploit the potential of marker technology it is utmost important to develop efficient and repeatable phenotyping techniques.

i) Development of nutrient use efficient genotypes

The duration of chickpea crop is very short (90-120 days) in southern and central India, where the soils are with poor fertility and shallow. The high yield can only be achieved from this part of the country if varieties with high nutrient use efficiency are developed and popularized. Most of the chickpea genotypes show excessive vegetative growth and subsequent crop lodging under high input management condition. There is need to develop genotypes which are efficient in making use of nutrients and irrigation water, especially for northern India where long growth period is available for chickpea. The genotypes efficient in nutrient use under rainfed condition may help in enhancing the productivity and will save critical farm inputs.

j) Drought

Characterization of drought is of utmost importance. There is need to define the drought to develop suitable plant types for moisture stress conditions from physiological view point. Breeding program should operate in close association with physiologists so that breeders can understand the physiological process involved in imparting resistance/tolerance and the physiologists about the requirement of breeding programs. Biotechnologists can also play significant role in assisting the program by way of integrating appropriate MAS technique with empirical selection.

k) High temperature tolerance

It is established fact that chickpea productivity suffers when temperature goes beyond 35^0C at reproductive stage. An empirical estimate suggest varying degrees of losses (8-12%) in productivity of chickpea during 2009-10 in different parts of the country including Rajasthan, Uttar Pradesh, Madhya Pradesh, Gujarat and Maharashtra. These losses can be even more in late sown crop when there is sudden rise in temperature at reproductive or pre-maturity stage of the crop. The preliminary studies on high temperature tolerance at Indian Institute of Pulses Research (IIPR) and International Crops Research Institute for the Semi-Arid

Tropics (ICRISAT), Patancheru have opened doors to develop high temperature tolerant chickpea cultivars. These studies have led identification of promising genotypes that showed high levels of heat tolerance both at Kanpur and Patancheru included ICCV 07104, ICCV 07105 and IPC 2006-99. These genotypes are being evaluated further for confirmation of their behavior with respect to heat tolerance during current crop season. Field screening resulted in identification of 4 promising genotypes with better drought tolerance.

l) Extra large seeded kabuli chickpea

To meet out the increasing demand and fulfill consumers' demand there is urgent need to develop extra large seeded (>50 g/100 seed weight) kabuli chickpea varieties which will fetch premium price in market and help in minimizing import of kabuli chickpea. This will ensure cultivation of chickpea in irrigated areas and will help in enhancing availability of more chickpea as well. During 2009, two such genotypes (Phule G 0517, PKV 4-1) have already been identified for release and cultivation in central India, which has opened doors for development of extra large seeded kabuli chickpea varieties.

To sum up

With the advent of biotechnological options and conventional ones, it has become possible to break yield barriers and achieve genetic enhancement for yield and quality traits in chickpea to ensure higher productivity. However, these options need careful implementation in harnessing synergies and capabilities available with various Institutions.

Table 1: Major diseases of chickpea in different states of India

States	Diseases
Eastern Uttar Pradesh, Bihar, Jharkhand, West Bengal, Assam	1. *Fusarium* wilt, dry and wet root rot 2. *Botrytis* gray mould
Punjab, Haryana, Himachal Pradesh, Jammu & Kashmir, Uttaranchal, North Rajasthan and western Uttar Pradesh	1. *Fusarium* wilt, dry and wet root rot 2. *Ascochyta* blight 3. *Botrytis* gray mould
Gujarat, Maharashtra, Madhya Pradesh, Chhattisgarh, part of Rajasthan	1. *Fusarium* wilt and dry root rots 2. Stunt virus
Andhra Pradesh, Karnataka, Tamil Nadu	1. *Fusarium* wilt 2. Stunt virus

- Gram pod borer in field and *Bruchids* during storage cause huge damage in all states

Table 2. Proposed plant types for various situations and zones

Zone	Condition	Major traits	Resistance/tolerance to
NWPZ	Irrigated	Medium tall to tall, erect plants, non-lodging, more basal upright branches, small and more leaflets per leaf, high harvest index, medium maturity duration	Wilt, root rot, *Ascochyta* blight, pod borer, cold at flowering, lodging
NWPZ	Rainfed	Medium tall, semi-erect, more pod on primary branches, profuse primary branching, small and more leaflets per leaf, rapid pod fill, medium maturity	Wilt, root rot, *Ascochyta* blight, pod borer, terminal soil moisture
NEPZ	Rainfed	Medium tall, semi-erect, more pod on primary branches, profuse primary branching, small and more leaflets per leaf, rapid pod fill, medium maturity	Wilt, root rots, botrytis gray mould, cold at flowering, terminal soil moisture
NWPZ NEPZ	Late sown	Medium tall, semi-erect, early maturity, early vigour, more basal branching, less tertiary branches	Wilt, root rot, pod borer, cold tolerance at vegetative stage, terminal heat
CZ & SZ	Rainfed	Medium tall, semi-erect, early vigour, more branches, early maturing	Wilt, root rot, pod borer, terminal heat and soil moisture stress

Table 3: Sources of resistance in wild Cicer species

Species	Sources of resistance against
C. arietinum	*Ascochyta* blight, *Fusarium* wilt, Leaf miner, Cold, Drought
C. chorassanicum	Leaf miner
C. cuneatum	Leaf miner, Seed beetle, *Ascochyta* blight
C. judaicum	Leaf miner, Seed beetle, *Ascochyta* blight, Cold
C. pinnatifidum	Leaf miner, Seed beetle, *Ascochyta* blight, Cold
C. reticulatum	*Fusarium* wilt, Seed beetle, Cold, *Ascochyta* blight
C. bijugum	*Ascochyta* blight, Cyst nematode, Seed beetle, Cold
C. echinospermum	Leaf miner, Seed beetle, Cold