

Chickpea (*Cicer arietinum*) research in India: accomplishments and future strategies

MASOOD ALI¹ and SHIV KUMAR²

Indian Institute of Pulses Research, Kanpur, Uttar Pradesh 208 024

Received: 15 February 2005

ABSTRACT

Chickpea or gram (*Cicer arietinum* L.) is the premier pulse crop of India, covering 7.29 million ha area. During the past 2 decades, chickpea output has gone up from 4.75 million tonnes to 5.77 million tonnes; mainly owing to yield gain of 130 kg/ha. Significant progress has been made in enhancing productivity, reducing duration, minimizing adverse impact of biotic stresses, improving seed size and expanding its cultivation in non-traditional areas by development of improved varieties, improved production and protection technologies, and identification of more remunerative and productive cropping systems. This has helped stabilize chickpea production in the country despite its cultivation being relegated to marginal environments. Past efforts have been rewarding in insulating varieties against biotic stresses by way of standardization of screening techniques, morphological characterization of causal agents, detection of racial differences, identification of donors, and understanding mechanism of resistance besides developing integrated pest management for *Helicoverpa* pod-borer and wilt. In spite of appreciable technological advances, major breakthrough in chickpea productivity is still elusive. To meet future demand of 7.37 million tonnes by 2010, the research strategy needs to be focused on the application of biotechnological tools for the pressing problems of *Helicoverpa* pod-borer and drought, marker-assisted selection and screening particularly for abiotic stresses, pyramiding of resistance genes, introgression of desired genes from wild species, development of efficient plant types for various cropping systems and agro-ecologies, and integrated management of stresses (pest, nutrient, water, weed, drought) in cropping system mode. Emphasis should also be given to identify new niches for expansion of the crop.

Key words: Chickpea, Integrated management, Production technology, Protection options, Varietal improvement

Chickpea or gram (*Cicer arietinum* L.) is an important pulse crop of the semi-arid tropics, particularly in the rainfed ecology of the Indian subcontinent, the Mediterranean region, the West Asian and North African region, Eastern Africa and Latin America. In the recent past, this crop has experienced an export-driven expansion in new niches such as Australia and Canada. Globally, chickpea is cultivated on about 10.4 million ha area adding 8.57 million tonnes of grains to the global food basket, with an average productivity of 826 kg/ha. As many as 45 countries grow chickpea but a dozen countries, viz India, Turkey, Pakistan, Iran, Mexico, Myanmar, Ethiopia, Australia, Spain, Canada, Syria and Morocco, contribute 96% to the global production. India grows chickpea on about 7.29 million ha, producing 5.77 million tonnes seed, which represents 30% and 38% of the national pulse acreage and production respectively. Chickpea production has gone up from 3.65 to 5.77 million tonnes between 1950–51 and 2003–2004, registering a growth of 0.58% annually. During the period,

while the area has marginally declined from 7.57 to 7.29 million ha, the yield has increased steadily to 792 kg/ha from 482 kg/ha. Notwithstanding its distribution throughout the country, 6 states, viz Madhya Pradesh, Uttar Pradesh, Maharashtra, Andhra Pradesh, Rajasthan and Karnataka, together contribute 93% of the production from 92% of area. Regional shift in chickpea area is most conspicuous. Over the past 3 decades, substantial expansion of chickpea in southern and central states has added 2.17 million ha, which is almost equal to the area loss (2.14 million ha) recorded in northern states. To achieve targeted production of 7.37 million tonnes by 2010, a two-pronged strategy involving horizontal expansion through crop diversification and productivity enhancement through strategic research is required.

The daily per caput availability of 14 g chickpea is a source of approximately 2.3% (56 Kcal) energy and 4.7% (2.7 g) protein to Indian population, besides being an important source of calcium and iron (10–12%). Germinated chickpea is reported to be effective in controlling cholesterol level in rats (Geervani 1991). Malic and oxalic acids secreted from leaves,

¹Director, ²Senior Scientist, Division of Crop Improvement

stems and pods have medicinal applications for aphrodisiac, bronchitis, catarrh, cutamenia, cholera, constipation, diarrhoea, digestive disorders, flatulence, snakebite, sunstroke and warts. These acids are known to lower blood cholesterol levels as well. Seeds are considered antibilious (Duke 1981). Chickpea also plays an important role in sustaining soil productivity by improving its physical, chemical and biological properties and trapping atmospheric nitrogen in their root nodules. A good crop of chickpea could fix up to 141 kg N/ha (Rupela 1987). The amount of biological nitrogen fixed by chickpea is, however, highly influenced by crop-management practices such as planting time, nutrient use and water management (Ali *et al.* 1998). Chickpea economizes nitrogen application for succeeding cereals to the tune of 56–68 kg N/ha (Ahlawat *et al.* 1981). With the development of short-duration varieties, chickpea has shown comparative advantage in crop diversification.

RESEARCH ACCOMPLISHMENTS

Significant progress has been made in chickpea particularly in minimizing adverse impact of biotic stresses, enhancing productivity, reducing crop duration, improving seed size and expanding its cultivation into non-traditional areas by development of improved varieties with matching production and protection technologies, and identification of more remunerative and productive cropping systems. This has helped stabilize chickpea production in the country despite its cultivation being relegated to marginal environments.

Genetic resource management

Chickpea is among the few pulse crops with rich genetic resources. The country holds a base collection of 11 726 accessions comprising indigenous (10 815) and exotic (911) stocks at the National Bureau of Plant Genetic Resources (NBPGR). The NBPGR also maintains active collection of 1 482 accessions at its Regional Station, Akola, this includes 858 exotic and 624 indigenous accessions. Further 13 452 accessions are maintained as working collections by various research centres of the All-India Co-ordinated Research Project on Chickpea (AICRPC). These are, however, repetitive in nature and include a number of duplicates. The Indian Institute of Pulses Research (IIPR) maintains 1 097 accessions and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) holds about 16 961 accessions, representing 44 countries, while International Centre for Agricultural Research in Dry Areas (ICARDA) maintains about 9 116 *kabuli* accessions from 34 countries. India has contributed about 40% to chickpea germplasm maintained at the ICRISAT with major share from Uttar Pradesh, Madhya Pradesh, Punjab and Maharashtra. About 135 accessions of 18 wild species of *Cicer* (8 annual and 10 perennial) have also been collected and maintained in these gene banks.

Evaluation of about 15 000 accessions for 25

morphological and yield attributes at the ICRISAT has revealed great genetic variability (Pundir *et al.* 1988). Similarly, *kabuli* germplasm maintained at the ICARDA was screened for 29 traits including reaction to major biotic and abiotic stresses; and promising donor sources have been identified (Singh *et al.* 1991). National efforts to evaluate chickpea germplasm systematically started as early as in 1972 when 1 353 accessions were evaluated at the Govind Ballabh Pant University of Agriculture and Technology (GBPUAT) Pantnagar, for different agro-morphological traits as well as for various biotic and abiotic stresses (Pandya and Pandey 1979). Similarly, at the Chaudhary Charan Singh Haryana Agricultural University (CCS HAU), Hisar, and Indian Agricultural Research Institute (IARI), New Delhi, 6 620 accessions comprising 1 803 indigenous and 4 817 exotic stocks from 21 countries were evaluated and promising accessions were identified (Lal and Tomer 1979). Later on, screening of 10 581 accessions at the GBPUAT, Pantnagar, was taken up to identify source of field resistance against *Botrytis* gray mold. About 8,000 accessions were screened at the Punjab Agricultural University (PAU), Ludhiana, against *Ascochyta* blight and *Botrytis* gray mold. Under the NBPGR-ICRISAT joint evaluation programme, 1 200 accessions were evaluated at the Regional Station, NBPGR, Jodhpur, and 6 600 at the Regional Station, NBPGR, Akola. Recently, Singh and Kumar (2004) have evaluated and characterized 1 097 germplasm accessions for 22 descriptors. A large number of promising donors for different traits have also been identified under the AICRPC. A mini-core collection of chickpea germplasm has been developed by the ICRISAT, which will help in better utilization of germplasm in breeding programme.

Varietal development

Research efforts made in the past through the National Agricultural Research System have led to the release of more than 125 varieties, which are adapted to varying agroclimatic conditions, and have in-built resistance against key biotic stresses prevalent in the chickpea-growing areas. From time-to-time, specific trials under the aegis of the AICRPC were constituted to meet specific targets such as bold-seeded *desi* and *kabuli* types, adaptation to late-sown condition, high-input condition and salt tolerance, resistance to *Fusarium* wilt and *Ascochyta* blight, and so on. Some centres like Indian Agricultural Research Institute (IARI) (17), Chandra Shekhar Azad University of Agriculture and Technology (CSAUAT) (15), Punjab Agricultural University (PAU) (15), Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV) (16), and agricultural universities of Maharashtra (18) have contributed as many as 60% of the total varieties released so far, which is testimony of their strong chickpea-breeding programmes.

Although chickpea breeders have been successful in improving cultivars, the use of limited germplasm has resulted in a rather narrow genetic base in the released varieties. The genetic base of chickpea is quite narrow as only 95 ancestors

are used for development of 86 varieties through hybridization following selection (Kumar *et al.* 2004). Moreover, relative contribution of the top 10 ancestors is as high as 35% in the total genetic base of the released varieties. The most frequently used ancestors are 'Pb 7', 'IP 58', 'F 8', 'Rabat' and 'S 26'. Based on the performance over years and locations of the varieties identified during different periods and subsequently included as checks in the AICRPC trials, the annual rate of genetic gain is estimated to be 6.5 kg/ha between 1975 and 2000. During the span of 25 years, a major share of the total genetic gain has occurred as a one-time increase of 72% during 1980–1985, with an annual rate of 23 kg/ha. The genetic gain in yield may be biased by the fact that yield performance was not always the sole criterion for release of the varieties. Quite a large number of varieties are released because chickpea breeders have modified other traits in addition to yield particularly resistance to key diseases, early maturity and large seed size besides specific adaptation to a particular situation.

Systematic breeding programmes in India have led to the development of resistant varieties against major diseases particularly *Fusarium* wilt and *Ascochyta* blight. A major breakthrough has been witnessed in developing bold-seeded *kabuli* varieties with high-yield potential such as 'KAK 2', 'BG 1003', 'BG 1053' and 'JKG 1'. Similarly, some of the prominent bold-seeded *desi* varieties developed are 'BG 256', 'Phule G 5', 'BG 391', 'K 850', 'Radhey', and 'Gujarat Gram 2'. Development of short-duration varieties has led to expansion of chickpea in new niches and non-traditional areas. Short-duration varieties like 'Annegiri', 'ICCV 2', 'JG 74', 'Pusa 372' and 'KAK 2' have been the major catalysts for expansion of chickpea in southern and central India. 'KPG 59', 'Pusa 256', 'PBG 1' and 'Pusa 372' have been suitable for late planting after the harvest of rice (*Oryza sativa* L.) in north India. In spite of reduction in duration, the yield potential of these early-maturing varieties remains almost unaffected thus improving per day productivity of the crop. Under excessive moisture and high input conditions, chickpea crop lodges due to excessive vegetative growth. Recently, a variety 'DCP 92-3' has been released for cultivation under high fertility and adequate moisture conditions. A salt-tolerant variety 'CSG 8962' ('Karnal Chana 1') has been developed for cultivation in irrigated areas having moderate salinity. Success has also been achieved in identifying drought-tolerant genotypes such as 'ICCV 10', 'Phule G 5', 'K 850', 'Vijay'.

Biotechnological interventions

Regeneration protocols in chickpea have been standardized specifically for utilization in genetic manipulation programmes. The most successful transformation systems in chickpea leading to recovery of transgenic plants have exploited embryonic axes using *Agrobacterium*-mediated transfer method (Fontana *et al.* 1993, Krishnamurthy *et al.* 2000). Chickpea cultivars 'ICCV 1' and 'ICCV 6' have been transformed with *Cry IA(c)* gene and a plasmid containing

nptII gene as the selection marker using gene gun (Kar *et al.* 1997). The ICRISAT, IARI, National Chemical Laboratory (NCL) and IIPR in India have comprehensive research programmes for development of transgenic plants possessing resistance to gram pod-borer. At the IIPR, transformed callus and plantlets possessing *nptII* gene have been obtained through *Agrobacterium*-mediated transformation (Mishra and Singh 2002). However, most of the transformation in chickpea is limited to the transfer of marker genes. Recently, the NCL has reported transmission of a recombinant gene to the progeny of transformed chickpea. However, rooting of transgenic shoots combined with poor shoot growth following rooting has been identified as the major barrier and needs to be resolved. The ICRISAT has developed transgenics for resistance to *Helicoverpa armigera* (Hubn.) using *Bt* genes, which is in the advanced stage (T4) of testing under contained facilities.

An integrated molecular map of chickpea genome has recently been established with a total of 354 markers including 18 STMSs, 96 DAFs, 70 AFLPs, 37 ISSRs, 17 RAPDs, 8 isozymes, 3 cDNAs, 2 SCARs and 3 loci, that confer resistance against different races of *Fusarium* wilt (Winter *et al.* 2000). Using Recombinant Inbred Lines (RILs), genes conferring resistance to race 1 and 4 of *Fusarium* wilt have been identified as closely linked to each other and to 2 random amplified polymorphic DNA (RAPD) markers, CS 27 and UBC 170. The reports that the genes for resistance to races 1, 4 and 5 of *Fusarium* wilt are located on linkage group 6 and the gene for resistance to race 0 is independent from them indicate clustering of several resistance genes (Winter *et al.* 2000). Recently, two quantitative trait loci (QTLs), conferring resistance to *Ascochyta* blight, are identified and molecular markers closely associated with these loci are also located (Santra *et al.* 2000). Efforts are on to map QTLs associated with tolerance to abiotic stresses and earliness. Selective genotyping for cold tolerance using amplified fragment length polymorphisms (AFLPs) is being investigated to identify putative genomic segments that contribute to cold tolerance. The first ever intra-specific genome map has been developed through collaboration between the ICRISAT and Washington State University, USA.

Wild species of chickpea are rich reservoir of not only resistance genes against various biotic and abiotic stresses but also for genes responsible for high yield, more seeds per pod and hybrid vigour. Conventional crossing has been successful in producing interspecific hybrids between *Cicer 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 prospects of transferring useful traits from tertiary gene pool in chickpea.

Production technologies

Chickpea is grown as the sole crop in various cropping

sequences and also as an intercrop with a number of cereals and oilseeds. To realize potential yield of improved varieties, research efforts have concomitantly been directed on various aspects of production input management such as nutrients, water, and of stress management such as weed and crop ecology. Past efforts have resulted in identification of most efficient sequential and intercropping systems involving chickpea. Chickpea + Indian mustard [*Brassica juncea* (L.) Czernj. & Cosson] in Indo-Gangetic plains, chickpea + linseed (*Linum usitatissimum* L.) in central zone, and chickpea + safflower (*Carthamus tinctorius* L.) or coriander (*Coriandrum sativum* L.) in southern zone have been found quite remunerative. Ali (1992) reported differential performance of chickpea genotypes under sole and intercropping systems, thus, adding new dimensions to the intercrop research such as genotypic compatibility and spatial arrangement of component crops. Chickpea cultivar, 'BG 261', has proved most compatible with Indian mustard following spatial arrangement of 4:1 at 30 cm spacing. In rainfed areas, chickpea 'JG 315' was found most compatible genotype for intercropping with Indian mustard cvs 'Vardan' and 'BG 256' with 'Neelam' linseed, following 6:2 row ratio. Planting in north-south row orientation is advantageous over east-west sowing. With the development of short-duration varieties of chickpea, new cropping sequences have emerged such as rice-chickpea, maize (*Zea mays* L.)-chickpea, sorghum [*Sorghum bicolor* (L.) Moench]-chickpea, pearl millet [*Pennisetum glaucum* (L.) R.Br. emend. Stuntz]-chickpea, cotton (*Gossypium* sp)-chickpea and sunflower (*Helianthus annuus* L.)- chickpea.

Chickpea removes, on an average, 91 kg N, 6 kg P, 49 kg K and 13 kg S/ha for giving 1.5 tonnes seed/ha (Acharya and Biswas 2002). Positive response to basal application of 15–20 kg N, 40–60 kg P₂O₅ and 20–60 kg K₂O/ha has been reported. In view of the biological nitrogen fixation, a starter dose of 15–20 kg N/ha has been recommended for the normal-sown rainfed chickpea. Similarly, in rice-based cropping systems on lowlands, late-sown chickpea generally responds well up to 40 kg N/ha (Ali and Mishra 1996). Foliar sprays of 2% diammonium phosphate or urea at pre-flowering stage enhanced yield by 25%. Among secondary nutrients, sulphur is now recognized as the most important nutrient for chickpea with yield gain of 7.6 to 25 kg/kg S. Experiments conducted on the alluvial soils at New Delhi showed that application of up to 40 kg S/ha enhanced nodulation by increasing number and dry weight of nodules, grain yield, nutrient uptake and crude protein in chickpea. The light-textured soils of north-west plains showed better response. Srinivasrao *et al.* (2003) reported 19% yield increase with 20 kg S/ha. Among micronutrients, positive responses to Zn, Mo, B and Fe have been reported from different parts of the country. Soil application of 15–20 kg ZnSO₄/ha or 2 foliar sprays of 0.5 kg ZnSO₄/ha has given encouraging response in terms of yield particularly in calcareous clay loam soils of foot-hills of Uttar

Pradesh and Bihar. In recent years, biofertilizers like N-fixing bacteria (*Rhizobium*), phosphorus-solubilizing bacteria (PSB) and vesicular arbuscular mycorrhiza (VAM) have been given due recognition in the integrated nutrient management, as they help in fixing atmospheric nitrogen, increasing native nutrient availability and improving nutrient cycling. Seed inoculation with an appropriate rhizobial strain increases nodulation, nitrogenase activity and yield. The productivity of chickpea can be enhanced by 10–15% by inoculating seeds with appropriate strain in different parts of India (Chandra and Ali 1986). Significant interaction of rhizobial strain with genotypes has also been observed (Patel *et al.* 1986). Use of phosphate-solubilizing bacteria along with phosphorus fertilizers shows positive impact on the grain yield.

Since chickpea is largely grown in rainfed areas, water management becomes critical for good harvest particularly in central and southern regions. Chickpea needs 15% soil moisture by volume in the root zone (Baldev 1988). Water-use efficiency can be improved with management practices such as change in sowing time, balanced nutrition, mulching and tillage. In limited surface moisture, pre-sowing irrigation and seed priming are desirable for proper germination. Irrigation at maximum branching and pod-development stages has given yield gains of 25–70%. Late-sown chickpea gives better response to irrigation than a normal sown crop (Ali 1994). The reproductive phase particularly pod development is the most critical stage with respect to moisture stress, and irrigation at this stage gives higher yields. Dhar and Singh (1995) used cumulative pan evaporation data to schedule irrigation of chickpea on a silty clay soil of Pantnagar. They found that irrigation scheduled at irrigation water : cumulative pan evaporation (IW : CWE) ratio of 0.6 gave a higher yield and water-use efficiency. Results at Kanpur showed that foliar spray of 2% KCl at flowering increased grain yield and water-use efficiency of chickpea (Ali 1985). Similarly, furrow placement of 2 kg *Jal Shakti*, a water-absorbing polymer, improves soil moisture and increases crop yield by 12%.

Weeds rob soil of nutrients and moisture, as chickpea is a poor competitor in early phase of crop development. Ali (1993a) found that period of first 8 weeks after sowing are critical for crop-weed competition. Among various herbicides, pre-emergence spray of pendimethalin at 1 to 1.5 kg/ha has been quite effective in controlling seasonal weeds. Manual weeding at 30 and 60 days after sowing is equally effective. Integration of lower dose of herbicides like 0.75 kg/ha of pendimethalin with 1 hand-weeding at 35–40 days after sowing has been found equally effective.

In the recent past, a paradigm shift in production system research has taken place with emphasis on cropping system mode, particularly after the emergence of ill-effect of cereal-based cropping systems. In rice-chickpea system, higher dose of 30–40 kg N/ha has been recommended. The beneficial effects of chickpea on succeeding cereals have been worked out. Ahlawat *et al.* (1981) noted that chickpea provides

equivalent of 60–70 kg N/ha to the following maize crop. Singh (1992) reported that application of phosphorus to chickpea was beneficial to succeeding rice giving a substitution effect of 20–30 kg P₂O₅/ha when compared with phosphorus applied to rice in rice–chickpea sequence. In chickpea + Indian mustard intercropping, application of 20 kg S and 30–60 kg P/ha has shown positive effect on seed and straw yields of chickpea as well as of Indian mustard. In chickpea + wheat (*Triticum aestivum* L. emend. Fiori & Paol.) system, recommended doses of fertilizers to wheat are sufficient to meet nutrient requirement of chickpea (Ali 1993b). In sequential cropping, time of sowing is of great importance, as it influences sowing of component crops. Efforts have also been directed to assess interaction of different production inputs. For example, phosphorus plays an important role in improving water-use efficiency. The relationship of phosphorus with irrigation is, therefore, important as well as multidimensional. Benefits from optimum irrigation regime and phosphorus are often synergistic.

Protection technologies

The main fungi that affect chickpea are *Fusarium oxysporum* sp. *ciceri* (Padw.) Matuo & Sato and *Ascochyta rabiei* (Pass.) Labrousse. Other fungi of significance are *Botrytis cinerea* Pers. ex Fr., *Rhizoctonia bataticola* Taub. & Butler, *R. solani* Kuhn, *Sclerotium rolfsii* Sacc., *Sclerotinia sclerotiorum* (Lib.) de Bary and *Alternaria* sp. Stunt disease caused by bean leaf roll virus, pea leaf roll virus and chickpea stunt luteovirus is also noticed in chickpea fields. A large number of plant-parasitic nematodes harbour on chickpea but 3 endoparasitic nematodes, viz. *Meloidogyne* spp, *Heterodera* spp and *Rotylenchulus reniformis* cause major damage to crop. Gram pod-borer (*Helicoverpa armigera* Hubner) is the

most dreaded insect pest of chickpea, and feeds on leaves and developing seeds. Cutworms (*Agrotis ipsilon* (Hufnagel), lesser armyworm [*Spodoptera exigua* (Hubn.)], leafminer, groundnut aphid (*Aphis craccivora* Koch), pea aphid [*Acyrtosiphon pisum* (Harris)], cowpea bean seed beetle [*Callosobruchus maculatus* (Fabr.)], and adzuki bean seed beetle [*C. chinensis* (L.)] are also important. Many storage insects specifically bruchid sp are serious pests of stored chickpea. Chickpea stored as *dhal* or *dal* harbours fewer bruchids. In general, estimates of yield losses by individual pests or diseases range from 5 to 10% in temperate regions and 50 to 100% in tropical regions (van Emden 1988).

Past efforts have been successful in morphological characterization of causal agents, standardization of screening techniques, detection of racial differences, identification of donors, understanding mechanism of resistance to key diseases and developing chemical-control practices. Physiological races of *Fusarium oxysporum* fsp. *ciceri* have been differentiated both by host range and biochemical tests. Seven physiological races (0–6) of the pathogen have been reported. Haware and Nene (1982) identified 4 races (1–4) in India. The pathosystem of *Ascochyta* seems to be very complex due to the presence of sexual phase. Using DNA molecular techniques, existing variability in the *Ascochyta* pathogen has been grouped into pathotypes I, II and III. Pathotypes I and II are reported from most places and pathotype III, which is most virulent, is not widely distributed. A large number of germplasm accessions have been screened using efficient and reliable field as well as laboratory screening techniques for *Fusarium* wilt and *Ascochyta* blight. Several reliable sources of resistance such as WR 315, ICC 11550, IC 2862, IC 10149, GL 91061, CPS 1, GL 8834, IPC 92-37, GL 86123,

Table 1 Improved varieties of chickpea with specific traits

Specific trait	Released varieties
Resistance to <i>Fusarium</i> wilt	'KWR 108', 'ICCV 10', 'H 82-2', 'CSG 8962', 'DCP 92-3', 'GCP 101', 'GCP 105', 'JG 315', 'GPF 2', 'Vijay', 'KGD 1168', 'JG 74', 'GNG 663', 'K 850', 'Radhey', 'BG 391', 'BG 212', 'KPG 59', 'BG 1003', 'BG 1053', 'Annigeri 1', 'Mahamaya 1', 'Vikas', 'BGD 72', 'Gaurav', 'PBG 1', 'GNG 469'
Tolerance to root-rot	'Alok', 'CO 3', 'KWR 108', 'Pusa 209', 'Pusa 240', 'Pusa 417', 'Pusa 413', 'Pusa 244', 'ICCV 6', 'ICCV 10', 'Pusa 372', 'Vijay', 'Vardan', 'Pusa 362', 'Pusa 391', 'GNG 469', 'CO 4', 'BGD 72', 'JG 11', 'L 551'
Tolerance to <i>Ascochyta</i> blight	'GNG 469', 'Gaurav', 'PBG 1', 'GNG 146', 'C 235', 'BG 261'
Tolerance to stunt	'Kiran', 'Pusa 244'
Tolerance to <i>Botrytis</i> gray-mold	'Pusa 209', 'ICCV 2', 'Gaurav'
Tolerance to root-knot nematode	'Kiran', 'Pusa 362', 'BGD 72'
Tolerance to <i>Helicoverpa</i> pod-borer	'Ujjain 24', 'ICCV 6', 'Vijay', 'Vardan', 'Vishal', 'BGD 72'
Drought tolerance	'CO 1', 'RS 10', 'Pant', 'G 114', 'Vikas', 'GNG 16', 'RSG 14', 'ICCV 10', 'Vijay'
Tolerance to salinity	'CSG 8962', 'ICCV 6'
Lodging resistant	'DCP 92-3', 'GNG 16', 'Pusa 240'
Wide adaptation	'C 235', 'L 550', 'Pusa 203', 'Pusa 209', 'Pusa 256', 'Pusa 372', 'Radhey'
Bold-seeded varieties	'BG 256', 'Phule', 'G 5', 'K 850', 'Radhey', 'GNG 469', 'BG 391', 'BGD 72', 'Pusa 362', 'Gaurav', 'Avrodhi', 'Co 3', 'Co 4', 'GG 2', 'ICCV 2', 'KAK 2', 'BG 1003', 'BG 1053', 'JKG 1', 'Phule G 95311'

H 86-18 for wilt; and ILC 200, ILC 6482, ICC 4475, ICC 6328, ICC 12004, E 100Y, E 100Y(M), BRG 8, NEC 206, GLG 84099, GLG 84038, ICC 1468 for *Ascochyta* blight have been identified. Use of resistant donors in breeding programmes has resulted in the development of resistant varieties against key pathogens (Table 1).

Development of chemical and bio-intensive protection technologies has helped reduce intensity and frequency of key diseases in the recent past. Several fungicides like thiram, benomyl, Calixin-M, Thiabendazole have been used as seed dressers and found effective in reducing seed-borne infection of *Ascochyta* blight. Seed treatment with carbendazim (0.25% w/w) together with carbosulfan (3% w/w) has not only been effective in reducing wilt incidence but has been found economical. Seed treatment with a combination of carbendazim and thiram (1:1), Hexacap, Captan, Captaf at 3 g and Rovral @ 2.5g/kg seed can control seed-borne pathogens. This can be supplemented with 2–3 foliar sprays of Hexacap, Captan, Captaf, Indofil M-45, Kavach at 350 g/0.4 ha in 100 litres water for controlling *Ascochyta* blight, and Dithane M-45 at 350 g, Thiabendazole, Bayleton, and Bayton at 200 g/0.4 ha in 100 litres water for *Botrytis* gray-mold. Antagonistic fungi like *Trichoderma viride* Pers.:Fr., *T. harzianum* Rifai and *Gliocladium virens* Miller, Giddens & Foster have been effective as biocontrol agents against all races of *Fusarium* wilt. Integration of seed treatment with *G. virens* (10 conidia/ml) and Carboxin (0.1%) against wilt complex under field conditions resulted in 29% increase in plant stand and 24% increase in yield. Controlling key diseases may require an integrated approach involving pathogen-free seeds, seed treatment, foliar spray with fungicides, a 3-year crop rotation and resistant cultivars. Late sowing and wide spacing help reduce severity of gray-mold. Seed soaking in aqueous extracts of oilseed cakes, viz neem (*Azadirachta indica* A. Juss.), Indian mustard and *karanj* (*Pongamia pinnata* Pierre) and leaf extracts of true hemp (*Cannabis sativa* L.), *bringaraja* [*Eclipta alba* (L.) Hassk.], *daustura* (*Datura metel* L.), prickly poppy (*Argemone maxicana* L. and neem reduce penetration of *Meloidogyne incognita* (Kofold & White) Chitwood juveniles (Mojumder and Mishra 1991, Tiyagi and Alam 1995). Integration of soil solarization for 6 weeks, VAM fungus and seed treatment with carbofuran (3% w/w) was effective in reducing *M. incognita* and wilt incidence. It was observed that population of root-knot nematodes declined significantly when seeds were treated with latex of *Calotropis procera* (Ait.) R. Br. at 1% v/w and neem seed powder at 5% w/w (IIPR 2004).

For management of pod-borer, different control measures have been tried. But when overall pest management scenario is considered with reference to whole ecosystem in which pest is causing devastating damage, the situation seems to be dismal. It has been increasingly realized that pest control by a single component alone cannot solve pest problem effectively and efficiently. Therefore, careful consideration

has been given in recent years to develop Integrated Pest Management systems approach that will be practical, economical and non-pollutant to environment. Such IPM systems have their utility under both the situations where insecticides have been indiscriminately used and where use of insecticides is not popular. Based on the concerted efforts of the past 2 decades, various measures, which can be effectively exploited for development of integrated pest management system for a particular locality, are as follows:

- Exploitation of host avoidance phenomenon through early sowing, i.e. by the end of October, under rainfed situations to avoid peak period of *Helicoverpa armigera* activity at podding stage, choosing short-duration cultivars and inter or mixed-cropping with Indian mustard, linseed, wheat and barley (*Hordeum vulgare* L., s.l.).
- Use of sex-pheromone traps and counting of eggs and larvae at reproductive stage between 10th and 16th standard weeks (north India) have been effective for monitoring pest activity. One larva/5–10 plants at flowering or podding is considered threshold level. A total of 5–6 moths/pheromone trap/day during March–April should be used as a warning signal for monitoring of eggs/larvae population.
- Plant products like neem-seed-kernel extract (5%) with 1% soap solution or use of neem-based commercial formulations like Neem gold, Neem-ark, Nimbecidine and Achook have been effective in controlling pests. Bio-agents like Ha-NPV at 250 LE/ha alone or in combination with half dose of endosulfan are equally effective.
- Eco-friendly pesticides such as endosulfan, fenvalerate and chlorpyrifos have been comparatively safer to *Campoletis chloridae*, a potential larval parasite of *H. armigera*. Insecticides like methomyl with ovicidal action may also be used. Insecticides of varied groups should be alternately used.
- Other components of management are installation of bird perches for encouraging insectivorous birds and inter-cultivation of nectar rich plants like coriander for improving level of parasitism on the eggs of *H. armigera*.
- Genotypes exhibiting moderate tolerance to pod-borer are 'ICC 5066', 'GL 645', 'PDG 84-10', 'RSG 888', 'PDE 2-3', 'PDE 2', 'ICC 10613', 'ICC 10619', 'ICCL 79048' and 'ICCL 84205'. 'ICCV 7' has been registered as a resistant source to gram pod-borer (Singh *et al.* 1997). Some of the released varieties like 'Vishal' and 'Vijay' have shown better tolerance to borer damage (Deshmukh *et al.* 1996a,b).

Management of abiotic stresses

Drought is considered to be the most important abiotic stress for chickpea production in rainfed areas. Other stresses of significance are cold, heat and salinity. Whatsoever success reported in breeding for tolerance to abiotic stresses (heat, drought, cool temperatures and salinity) is involuntary in a

sense that the yield performance of the promising breeding lines evaluated over many seasons and locations led to identification of tolerant varieties to various abiotic stresses. *Per-se* tolerance to abiotic stresses appears to be a difficult proposition due to several technical limitations. Early plant vigour, fast ground cover and large seed size besides high root biomass, long and deep root-system, high leaf water potential, better osmotic adjustment, high water-use efficiency and small leaflets are some of the attribute that show significant association with drought tolerance, and high harvest index, large number of pods per unit area and high grain mass along with early maturity are associated with drought escape. Regulation of cellular turgor pressure and hydration through osmotic adjustment have shown to increase yield potential of chickpea up to 20% under water-deficit environments. 'C 235' is found to be a good osmoregulator. However, lack of a simple repeatable large-scale screening technique has been the major obstacle in breeding for drought tolerance. Two drought tolerant lines, 'ICC 4958' and 'ICC 10488' have been the result of screening under irrigated and non-irrigation conditions (Saxena 1987). 'ICC 4958' showed drought tolerance due to exceptionally high root volume. Under the Indian Council of Agricultural Research (ICAR) and Australian Centre for International Agricultural Research (ACIAR) collaborative project, about 70 genotypes have been evaluated for identification of traits associated with higher yield under drought-prone environments of India (7 locations) and Australia (5 locations). Pod number, harvest index and biomass have been identified as dominating factors for higher yield, and morpho-physiological parameters such as high root volume, osmotic adjustment and sucrose synthase have been associated with drought tolerance.

Chickpea is highly sensitive to mean temperatures below 15°C at flowering stage leading to flower abortion. Hence any advantage derived from early flowering is negated by flower and pod loss due to low temperature (0–5°C), which is of common occurrence for about 15–20 days in the northern states. Search for donors, which can retain flowers and set pods under low temperature has led to identification of 'M 450', 'ICCV 88501', 'ICCV 88502', 'ICCV 88503', 'ICCV 88506' and 'ILC 8262'. Several introductions from Russia and wild species have shown fairly good level of cold tolerance. Prevalence of temperatures above 30°C especially during the reproductive stage and soil salinity throughout the life-cycle mainly because of improper water management cause severe stress to crop. Continuous efforts on screening genotypes have led to identification of tolerant sources ('ICCV 92944' and 'ICCV 830107'), and salinity ('CSG 8893', 'E100Y', 'CSG 8894', 'H 89-84', 'H 81-69' and 'H 85-10') for high temperature.

FUTURE STRATEGY

In spite of appreciable technological advances in chickpea, major breakthrough in its productivity is yet to be witnessed. The present level of production is not sufficient to

meet the domestic demand, leading to substantial import of chickpea. A target of 7.37 million tonnes of chickpea is set for 2010. To meet future projection, the research strategy needs to be focussed on the following options.

Genetic options

1. Development of efficient plant types suitable for different agro-ecological zones and cropping systems.
2. Deployment of resistance genes in spatial and temporal manner through gene pyramiding.
3. Development of varieties with multiple resistance and multi-gene resistance to key diseases and insect pests.
4. Development of genotypes with tolerance to abiotic stresses.
5. Development of nutrient responsive and nutrient-use efficient genotypes.
6. Introgression of desirable genes from wild species to broaden genetic base of cultivated germplasm.
7. Multilocation evaluation of germplasm and their utilization.
8. Development of transgenics particularly for resistance to gram pod-borer.
9. Development of integrated and well-distributed linkage map.
10. Molecular mapping of economically important genes and their precise transfer through marker-aided selection.

Production options

1. Refinement of chickpea-production technology for introduction in cereal-based intensive cropping systems.
2. Development of agro-technologies for chickpea under rice fallows.
3. Integrated nutrient and water management system for chickpea-based cropping systems.
4. Tillage and population management in rainfed areas.
5. Development of an integrated weed management system with ecological and bioherbicidal approach.
6. Identification of morpho-physiological and biochemical traits associated with cold, heat and drought tolerance.
7. Isolation and identification of efficient *Rhizobium* and PSB for higher productivity.
8. In-depth research on management aspects of the intercrops especially on nutrient management, weed management and allelopathic effects of the component crops.
9. Research on plant-microbe-climate-soil interactions for nitrogen fixation.

Protection options

1. Development and refinement of IPM modules against gram pod-borer.
2. Mechanism of resistance to major biotic stresses.

3. Development of prediction models and computer-based forecasting models for key diseases and insect pests.
4. Molecular characterization of pathogenic variability of key pathogens.
5. Exploitation of biological agents in key diseases management.
6. Identification of race specific and multiple race resistant donors.
7. Development of integrated nematode-management modules.

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