Series of Crop Specific Biology Documents

BIOLOGY OF *CICER ARIETINUM* (CHICKPEA)

Phase II Capacity Building Project on Biosafety

Ministry of Environment, Forest and Climate Change

Government of India

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Biology of *Cicer arietinum* (Chickpea)

Prepared by :

Ministry of Environment, Forest and Climate Change (MoEF&CC)
and jointly with Indian Institute of Pulses Research, Kanpur and International Crops Research Institute for the Semi-Arid Tropics, Hyderabad under UNEP/GEF supported Phase II Capacity Building Project on Biosafety

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सत्यमेव जयते

Message

I am happy to learn that the Ministry of Environment, Forest & Climate Change (MoEFCC) as part of the initiative under the UNEP GEF supported "Phase II Capacity Building Project on Biosafety" has developed eight crop specific biology document on Chickpea, Mustard, Papaya, Pigeon-pea, Potato, Rubber, Sorghum, and Tomato.

I am happy to note that the documents have been prepared with support from seven research institutions namely Indian Institute of Pulses Research, Directorate of Rapeseed and Mustard Research, Indian Institute of Horticulture Research, Central Potato Research Institute, Rubber Research Institute of India, Indian Institute of Millets Research and Indian Institute of Vegetable Research.

While Bt cotton is the only genetically modified (GM) crop approved for commercial cultivation in India, there are several crops under various stages of research, development and field trials. The present set of crop specific biology documents aims to provide scientific baseline information of a particular plant species that can be used as credible source of information for conducting safety assessment of GM plants.

I would like to congratulate all those who were involved in preparing these documents and those involved in steering this initiative.

I am confident that these biology documents will serve as a valuable tool for regulators, scientists, crop developers, policymakers, academicians and other stakeholders who are involved in the safety assessment of GM plants. I am also hopeful that baseline information provided in the biology document would further enhance awareness on biosafety aspects of GM crops.

(Prakash Javadekar)

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PREFACE

India is an agriculture based economy with abundance of genetic base, diverse agro-climatic zones and highly qualified manpower which provides a rich scope for technological advances in agricultural biotechnology. The shortage of healthy seeds/planting material, lack of disease resistant clones, crop damage by insects, pests etc. have often affected the Indian agricultural economy adversely and therefore the role of new technologies assumes significant importance for Indian economy.

With significant advances in the field of agricultural biotechnology the regulatory system has to deal with multiple crops integrated with multiple traits. In order to streamline the process of safety assessment, the Ministry of Environment, Forest & Climate Change (MoEF&CC) under the UNEP-GEF supported "Phase II Capacity Building Project on Biosafety" has prepared a set of crop specific biology documents namely Chickpea, Mustard, Papaya, Pigeon-Pea, Potato, Rubber, Sorghum, Tomato with support from six Indian Council of Agriculture Research (ICAR) institutions and Rubber Research Institute of India.

The biology documents provides an overview of baseline biological information of a particular plant species such as taxonomy, the centres of origin, its related species including wild relatives, general description of their morphology, reproductive biology, biochemistry, potential for gene introgression, biotic and abiotic interactions. Such species specific information is expected to serve as a guiding tool for use in risk assessment of genetically modified (GM) plants.

The documents has been prepared through a consultative approach and comments received from several organizations have been extremely useful in validating this document. I express my deep appreciation for the support provided by Indian Institute of Pulses Research, Directorate of Rapeseed and Mustard Research, Indian Institute of Horticulture Research, Central Potato Research Institute, Rubber Research Institute of India, Indian Institute of Millets Research and Indian Institute of Vegetable Research in preparing these documents. I would also like congratulate Dr. Ranjini Warrier, Advisor, (MoEFCC) and Dr O.P Govila (Former Professor, Department of Genetics, IARI) for their sincere efforts and the consultative approach adopted in finalizing the biology documents.

I am confident that these crop specific biology documents would be of immense value for researchers, regulators and industry in planning for the safety assessment of GM crops.

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BIOLOGY OF *Cicer arietinum L.* (CHICKPEA)

1. INTRODUCTION

1.1 General Description

Chickpea, *Cicer arietinum* L. belongs to the family Fabaceae, within the tribe *Cicerae*. It is a self-pollinated, diploid, annual grain legume crop. The global production of chickpea is nearly 11 million tonnes and India is the major producer accounting for 64% of the total chickpea production (FAOSTAT, 2012). It is a major source of high quality protein in human diet and also provides high quality crop residues for animal feed.

Chickpea is classified into two broad types, *desi* and *kabuli*. Most of the desi types are small in size, angular in shape with dark seed color and rough seed coat, while kabuli have large beaked seeds with white or beige seed coat colour and larger in size with smoother seed coat. Kabuli type chickpea is mostly grown in the temperate regions, while the Desi type chickpea is grown in the semi-arid tropics (Muehlbauer and Singh, 1987; Malhotra *et al.*, 1987). However, several early-maturing Kabuli chickpea varieties have been developed recently, which can be cultivated in tropical regions (Gaur *et al.* 2005).

Among the temperate pulses, chickpea is the most tolerant crop to heat and drought stress and is suitable for cultivation in low fertility soils. Chickpea also helps to maintain soil fertility through biological nitrogen fixation and contributes to the sustainability of cropping systems in the cereal-legume crop rotations. Chickpea crop meets 80% of its nitrogen (N) requirement from symbiotic nitrogen fixation and can fix up to 140 kg N ha/1 from air. It leaves a substantial amount of residual nitrogen for subsequent crops and adds plenty of organic matter to maintain and improve soil health. Because of its deep tap root system, chickpea can withstand extended periods of drought by extracting water from deeper layers of the soil.

Chickpea is eaten fresh as a green vegetable or parched, fried, roasted, or boiled seeds. Dal (split chickpea without seedcoat) and flour are used extensively in India as a thick soup for making breads. Sprouted seeds are eaten as a vegetable or added to salads. Young seedlings and green pods are also eaten. Chickpea seeds may be milled or directly used for animal feed. Leaves yield an indigo like dye. Acid exudates from the leaves can be used as a medicine or used as vinegar. Chickpea seeds contain 21% starch, which is suitable for textile sizing, giving light finish to silk, wool and cotton cloth (Duke, 1981).

Chickpea is grown in more than 50 countries (89.7% area in Asia, 4.3% in Africa, 2.6% in Oceania, 2.9% in the Americas and 0.4% in Europe). India is the largest producer accounting for 64% of the total chickpea production (Fig. 1).

The other major chickpea producing countries are Pakistan, Turkey, Iran, Myanmar, Australia, Ethiopia, Canada, Mexico and Iraq.

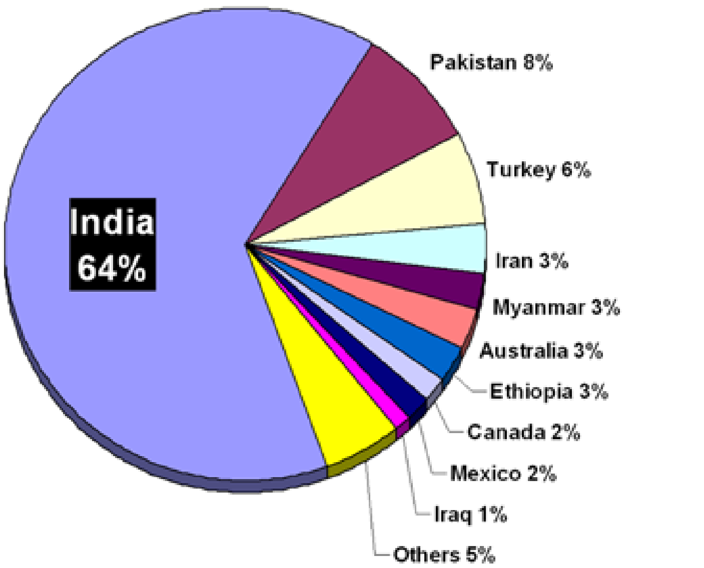

Fig. 1. Share of different countries in chickpea production (2005 to 2007).

Chickpea is an important source of protein for millions of people in the developing countries, particularly in South Asia, who are largely vegetarian in food habits. In addition to having high protein content (20 - 22%), chickpea is rich in fiber, minerals (phosphorus, calcium, magnesium, iron and zinc) and β-carotene. Its lipid fraction is rich in unsaturated fatty acids.

In India, the major chickpea production areas are in Madhya Pradesh, Rajasthan, Uttar Pradesh, Haryana, Maharashtra, Telangana, Andhra Pradesh, Karnataka and Punjab. It is a hardy crop and can be grown on marginal lands where the high-input crops fail to give economic returns. Chickpea is a high-value crop and plays a vital role in crop diversification and economic viability of the farming systems. High economic returns can be obtained from chickpea cultivation with the adoption of integrated pest management (IPM) and integrated crop management (ICM) practices.

1.2 Nutritional Value of Chickpea

Chickpea is an excellent source of essential nutrients, protein, minerals, fiber, unsaturated fatty acids and β-carotene (Table 1). Chickpea is considered as one of the most nutritious food grain legumes for human consumption with potential health benefits. High fiber content in chickpea has the ability to lower cholesterol and prevent blood sugar levels from rising too rapidly after a meal and thus, making it a healthy food for diabetic patients. Chickpea also contains raffinose-type oligosaccharides, which cause flatulence. However, these effects can be neutralized by boiling or soaking the seeds in water.

The nutrient profile of the chickpea varieties with smaller seeds is different, especially in fiber content, which is higher than the varieties with larger light colored seeds. In general, the cotyledons and embryo make up most of the nutritionally beneficial part of the seed, while the seed coat contains many of the anti-nutritional factors (ANFs). The Desi types have a thicker seed coat than the Kabuli types, which is reflected in greater fiber content of the Desi types (Knights and Mailer, 1989).

Table 1.Nutritional composition of chickpea seeds

Nutrient	All values are per 100gms of edible portion
Moisture (g)	9.8
Protein (g)	17.1
Fat (g)	5.3
Minerals (g)	3.0
Crude fibre (g)	3.9
Carbohydrates (g)	60.9
Energy (Kcal)	360
Calcium (mg)	202
Phosphorus (mg)	312
Iron (mg)	4.6
(**Source:** National Institute of Nutrition, 2007)	

2. TAXONOMY, GEOGRAPHIC ORIGIN AND GENOMIC EVOLUTION

2.1 Taxonomy

The Taxonomic classification of *C. arietinum* is given in the table below:

Name	Chickpea
Kingdom:	Plantae
(unranked):	Angiosperms
(unranked):	Eudicots
(unranked):	Rosids
Order:	Fabales
Family:	Fabaceae
Genus:	*Cicer*
Species:	*Cicer arietinum*

Based on the Harlan and de Wet (1971) gene pool (GP) concept, the chickpea genepool may be characterized as follows. Species in GP1b are most closely related to chickpea and those in GP2 and GP3 are distantly related to chickpea (Kupicha, 1977).

GP1a	GP1b	GP2	GP3
Cicer arietinum *C. reti-culatum*	*C. echino-spermum*	*C. bijugum* *C. judaicum* *C. pinna-tifidum*	*Other Cicer species*

2.2 Geographical Origin and Distribution

Chickpea is one of the earliest grown grain legume crop domesticated in the Old World at Tell el-Kerkh (10th millennium BC) in Syria, Cayönü (7,250 - 6,750 BC), Hacilar (ca 6,700 BC) and Akarcay Tepe (7,280 - 8,700 BC) in Turkey and Jericho (8,350 - 7,370 BC) in the West Bank. Ladizinsky (1975) reported that the center of origin of chickpea is southeastern Turkey. However, van der Maesen (1972, 1987) recognized southeastern part of Turkey adjoining Syria as the possible center of origin of chickpea based on the presence of closely related annual species, *C. reticulatum* and *C. echinospermum*. Most probably, chickpea originated in South Eastern Turkey and Syria, where three annual wild *Cicer species*, *C. bijugum*, *C. echinospermum* and *C. reticulatum* have been found in the wild habitats. Chickpea spread to the West and South via the Silk Route with human migration (Singh *et al.*, 1997). Four centers of chickpea diversity have been identified in the Mediterranean, Central Asia, Near East and India, while a secondary center of origin has been reported in Ethiopia (Vavilov, 1951). Wild *C. reticulatum* is interfertile, but closely resembles chickpea. It is regarded as the wild progenitor of chickpea (Ladizinsky, 1975). Botanical and archeological evidence has shown that chickpeas were first domesticated in the Middle East and widely cultivated in India, Mediterranean, Middle East and Ethiopia since antiquity. Brought to the New World, it is now an important crop in Mexico, Argentina, Chile, Peru, Canada, USA and Australia. Wild species are most abundant in Turkey, Iran, Afghanistan and Central Asia (Duke, 1981).

Cicer species occurs from sea level (*C. arietinum* and *C. montbretii*) to over 5,000 m above mean sea level (*C. microphyllum*) near glaciers in the Himalayas. The cultivated species, *C. arietinum* can not colonize successfully without human intervention. The wild species (*C. reticulatum* and *C. bijugum*) occur in weedy habitats (fallow or disturbed habitats, roadsides, cultivated fields of wheat and other places not touched by man or cattle), mountain slopes among rubble (*C. pungens* and *C. yamashitae*), on forest soils, in broad-leaf or pine forests (*C. montbretii* and *C. floribundum*) and in stony and desert areas in the Himalayas in India (*C. microphyllum*) (Chandel, 1984).

2.3 Chickpea Gene Pool and Species Complex

There has been an increasing demand for high yielding, disease, insect and drought-resistant cultivars of chickpea. Wild relatives of chickpea have been used to access genes for resistance/ tolerance to biotic and abiotic stress factors (van der Maesen *et al.*, 2006; Kupicha, 1977). The emphasis has primarily been on species that are closest to the cultivated chickpea. The threat status for *Cicer* species in the wild has not been systematically reviewed, but six *Cicer* species were included in the 1997 World Conservation Union (IUCN) list of threatened plants (Walter and Gillett, 1998) using the pre-1994 categories. The six species C. atlanticum, *C. echinospermum, C. floribundum, C. graecum, C. isauricum* and *C. reticulatum* were categorized as rare (R). The ecogeography and conservation status of *Cicer* species was recently reviewed by Hannon *et al.* (2001). Major international *Cicer ex situ* collections (Berger *et al.*, 2003) are being maintained at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India (17,244 accessions), the International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria (9,682 accessions, 292 wild accessions) and at the US Department of Agriculture, Agricultural Research Service (USDA-ARS), Western Regional Plant Introduction Station (WRPIS), Pullman, Washington (4,602 accessions) (Hannon *et al.*, 2001). There is little information on *in situ* conservation of wild *Cicer* species. Although these species occur in the protected areas, their maintenance is not the focus of the reserve management plan. One rare species of wild chickpeas is under *in situ* conservation in Bulgaria (Gass *et al.*, 1996; Hannon *et al.*, 2001), but widespread loss of actual wild species habitats in areas considered to be the centres of diversity for *Cicer* has occurred in the recent past.

Since 1972, only four species have been described as new to science: *C. heterophyllum* (Contandriopoulos *et al.*, 1972; Javadi and Yamaguchi, 2004.), *C. reticulatum* (Ladizinsky, 1975) and *C. canariense* (Santos Guerra and Lewis, 1985), which was sufficiently distinct to warrant monospecific subgenus, *Stenophylloma* and *C. luteum* (Rassulova and Sharipova, 1992). In recent years, collection of wild *Cicer spp*. has become more difficult because of the uncertainties about the execution of new biodiversity access and benefit sharing (van der Maesen *et al.*, 2006). Current interest in wild relatives and addition of new taxa has resulted in improved identification aids to enable accurate identification of the currently described *Cicer* taxa. The species descriptions and eco-geographic notes are given in Table 2.

Table 2. Species descriptions with Eco-Geographic notes.

SN	Name of species	Growth habit	Life cycle	Remarks
1	*C. acanthophyllum*	Erect or shrubby	Perennial	Afghanistan, India (Kashmir), N Pakistan, Tadzhikistan; 2500–4000 m.
2	*C. anatolicum* (2n= 14,16.)	Erect	Perennial	Armenia, NW and W Iran, N Iraq, Turkey; 500–4200 m
3	*C. arietinum* (2n=14,16,24,32,33.)	Erect	Annual	Wide spread in cultivation in semiarid tropics and warm temperate zones; (0-)110-2400 m
4	*C. atlanticum*	Prostrate	Perennial	Morocco; 2700–2900 m
5	*C. balcaricum*	Erect or shrubby	Perennial	Armenia, Azerbaijan, Georgia; 2000 m
6	*C. baldshuanicum*	Erect	Perennial	Tadzhikistan; 1600–2000 m
7	*C. bijugum* (2n=16)	Prostrate to erect	Annual	N,W Iran, N Iraq, N Syria, SE Turkey; 500–1300 m
8	*C. canariense* (2n=16, 24)	Scrambling	Perennial	Canary Islands, La Palma and Tenerife; 900–1400 m
9	*C. chorassanicum* (2n=16)	Prostrate to erect	Annual	N and C Afghanistan, N and NE Iran; 1400–3300 m
10	*C. cuneatum* (2n=16)	Erect or climbing	Annual	Egypt, Ethiopia, Saudi Arabia; 1000–2200 m
11	*C. echinospermum* (2n=16)	Prostrate to erect	Annual	N Iraq, Turkey; 600–1100 m
12	*C. fedtschenkoi*	Erect	Perennial	N and NE Afghanistan, Iran, S Kirghizistan, Tadzhikistan; 2500–4200 m
13	*C. flexuosum*	Erect or shrubby	Perennial	Skirgizistan, Tadzhikistan,Uzbekistan; 500–2400 m.
14	*C. floribundum* (2n= 14)	Erect	Perennial	S Turkey; 800–1700 m
15	*C. graecum*	Erect	Perennial	Greece; 1000–1400 m
16	*C. grande*	Erect	Perennial	Uzbekistan; 1000–2000 m
17	*C. heterophyllum* (2n=16)	Erect	Perennial	Turkey; 1100 m
18	*C. incanum*	Erect	Perennial	Tadzhikistan; 2000–3000 m
19	*C. incisum*	Prostrate	Perennial	Armenia, Greece (including Crete), Georgia, Iran, Lebanon, Syria, Turkey; 1400–2740 m.
20	*C. isauricum* (2n= 16)	erect	Perennial	S Turkey; 1000–1750 m
21	*C. judaicum* (2n= 16)	Prostrate to erect	Annual	Israel, Lebanon; 0–500 m
22	*C. kermanense*	Erect or shrubby	Perennial	SE Iran; 2300–3300 m
23	*C. korshinskyi*	Erect	Perennial	Iran, Tadzhikistan; 2500–2600 m
24	*C. laetum*	Erect or ascendant	Perennial	Tadzhikistan, East Pamir-Alai, 2500 m
25	*C. luteum*	Erect	Perennial	Tadzhikistan; 3900–4000 m
26	*C. macracanthum*	Erect	Perennial	Afghanistan, India (Kashmir), Iran, N Pakistan, Tadzhikistan, Turkestan, Uzbekistan; (1200–) 2743–4250 m
27	*C. microphyllum* (2n=14,16)	Erect	Perennial	E Afghanistan, China, India (Kashmir), Nepal, Pakistan, Tadzhikistan; (2000–)2500–4600(–5600) m
28	*C. mogoltavicum*	Shrubby	Perennial	Tadzhikistan; 1500 m
29	*C. montbretii* (2n=16, 24)	Erect	Perennial	S Albania, SE Bulgaria, N Greece, European and Aegean Turkey; 0–1200 m
30	*C. multijugum*	Erect	Perennial	Afghanistan; 3000–4200 m
31	*C. nuristanicum*	Erect	Perennial	E Afghanistan, India (Kashmir), N Pakistan; 2134–4600 m
32	*C. oxyodon*	Erect	Perennial	Afghanistan, Iran, N Iraq; 500–2980 m

33	*C. paucijugum*	Erect	Perennial	E Kazakhstan, Tadzhikistan; 2900 m
34	*C. pinnatifidum*	Prostrate to erect	Annual	Armenia, N Iraq, N Syria, Turkey; 250–1500 m
35	*C. pungens* (2n=14)	Flexuous, erect, spiny	Perennial	Afghanistan, W Tadzhikistan; (1800–)2300–4200 m
36	*C. rassuloviae*		Perennial	Tadzhikistan, W Pamir-Alai, endemic; 1700 m
37	*C. rechingeri*		Perennial	Afghanistan, endemic; 2400–3600 m.
38	*C. reticulatum* (2n=16)	Prostrate to erect	Annual	Turkey; 650–1100 m
39	*C. songaricum*	Erect or shrubby	Perennial	E Kazakhstan, Kirghizistan, Tadzhikistan, Uzbekistan; 1000–4000 m
40	*C. spiroceras*	Erect or shrubby	Perennial	Iran; 1600–3500 m
41	*C. stapfianum*	Shrubby	Perennial	Iran; 4000 m
42	*C. subaphyllum*	Erect or shrubby	Perennial	Iran; 4000 m
43	*C. tragacanthoides*	Erect	Perennial	Afghanistan, Iran, S Turkmenia; 1500–3800 m
43a	*C. tragacanthoides var. tragacanthoides*	Erect	Perennial	Afghanistan, Iran, S Turkmenia; 1500–3800 m
43b	*C. tragacanthoides var. Turcomanicum*	Erect	Perennial	Iran, S Turkmenia; 1500–3000 m
44	*C. yamashitae* (2n=16)	Prostrate to Erect	Annual	Afghanistan; 900–2800 m

2.4 Germplasm Diversity

The chickpea germplasm is being maintained by several institutes in different countries (Sharma *et al.*, 2013) (Table 3). Although a large number of cultivated and wild chickpea accessions are available, there is a large void in utilizing these accessions in the breeding programs. The major limitation preventing their utilization has been lack of information on major economic traits. Additionally, screening of large number of germplasm lines in multi location trials is both expensive and time consuming. After evaluating about 16,990 chickpea accessions for 13 traits, a core collection of 1,956 accessions has been developed at ICRISAT (Upadhyaya *et al.*, 2001). A mini-core collection of 211 chickpea accessions has also been developed (Upadhyaya and Ortiz, 2001). A reference set of 300 lines has been developed jointly by ICRISAT and ICARDA under the Generation Challenge Program (GCP) to represent the genetic variability in chickpea germplasm (Upadhyaya *et al.*, 2008). The core, mini-core and reference sets of the germplasm provide cost-effective and manageable entry points to initiate screening for different traits (Glaszmann *et al.*, 2010). With the objective of trait mapping using genome-wide association studies, the reference set of chickpea is being genotyped with a large number of Diversity Arrays Technology (DArT) and single nucleotide polymarphisms (SNP) markers and is also being phenotyped for many traits, both in the field and under controlled environmental conditions.

Table 3. Chickpea Germplasm held in Various Research Institutes Globally

Country	Institute	Wild accessions	Wild species	Cultivated accessions	Total
Australia	Australian Temperate Field Crops Collection (ATFCC), Horsham, Victoria	246	18	8,409	8,673
Ethiopia	Institute of Biodiversity Conservation (IBC), Addis Ababa			1,173	1,173
Hungary	Institute for Agrobotany (RCA), Tápiószele	9	5	1,161	1,175
India	ICAR - Indian Agricultural Research Institute (IARI), New Delhi			2,000	2,000
	International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Hyderabad	308	18	19,959	20,285
	ICAR - National Bureau of Plant Genetic Resources (NBPGR), New Delhi	69	10	16,812	16,891
Iran	College of Agriculture, Tehran University, Karaj			1,200	1,200
	National Plant Gene Bank of Iran, Seed and Plant Improvement Institute (NPGBI-SPII), Karaj			5,700	5,700
Mexico	Estación de Iguala, Instituto Nacional de Investigaciones Agrícolas (IA-Iguala), Iguala			1,600	1,600
Pakistan	Plant Genetic Resources Institute (PGRP), Islamabad	89	3 (1)	2,057	2,149
Russian Federation	N.I. Vavilov All-Russian Scientific Research Institute of Plant Industry (VIR), St. Petersburg			2,091	2,091
Syria	International Centre for Agricultural Research in Dry Areas (ICARDA), Aleppo	270	11 (1)	13,548	13,829
Turkey	Plant Genetic Resources Department, Aegean Agricultural Research Institute (AARI), Izmir	21	4	2,054	2,079
Ukraine	Institute of Plant Production n.a. V.Y. Yurjev of UAAS, Kharkiv			1,021	1,021
USA	Western Regional Plant Introduction Station, USDA-ARS, Pullman	205	22	6,584	6,811
Uzbekistan	Uzbek Research Institute of Plant Industry (UzRIPI), Botanica			1,055	1,055

Source: http://apps3.fao.org/wiews/germplasm_query.htm?i_l=EN

3. GENERAL PLANT CHARACTERISTICS

Chickpea is a herbaceous annual and the plant height ranges from 30 - 70 cm. It has a tap root system, which is deep and strong. The lateral roots develop symbiotic nodules with the *Rhizobium* bacteria, which are capable of fixing atmospheric nitrogen in plant-usable form. The nodules (slightly flattened fan-like lobes) are visible about one month after seedling emergence and are confined to the top 15 cm of the soil surface. The leaves are imparipinnate with serrated leaflets and arise alternatively from the third node. The number of leaflets varies from 5 to 17. However, some varieties have simple leaves. The entire surface of the plant, except the corolla, is densely covered with fine hairs known as trichomes, which are glandular and secrete a highly acidic exudate containing malic, oxalic and citric acids. These acids play an important role in protecting the plant against insect-pests (Sharma *et al.*, 2008; Narayanamma *et al.*, 2008). The plants have primary (generally 1 - 8), secondary and tertiary branches. Five growth habits, based on angle of branches from the vertical stem are: erect, semi-erect, semi-spreading, spreading and prostrate. The erect and semi-erect varieties are suitable for mechanical harvesting.

Based on seed size and color, cultivated chickpeas are of two types (Fig. 2).

Microsperma (Desi chickpea): Chickpeas with colored and thick seed coat are called Desi type. The seeds have a combination of brown, yellow, green and black colors. The seeds are generally small and angular with a rough surface. There are 2 - 3 ovules in each pod, but 1 - 2 seeds are produced per pod. The plants are short with small leaflets. The flowers are generally pink and the plants show various degrees of anthocyanin pigmentation, although some Desi types have white flowers, but there is no anthocyanin pigmentation on the stem. The Desi types account for 80 - 85% of the chickpea area. The split seeds (dal) and floor (besan) are invariably made from Desi type chickpeas.

Macrosperma (Kabuli chickpea): The Kabuli type chickpeas are characterized by white or beige-colored seed with a ram's head shape, thin seed coat, smooth seed surface. The plant is medium to tall in height, with large leaflets and white flowers and contains no anthocyanin. As compared to the Desi types, the Kabuli types have higher levels of sucrose and lower levels of fiber.

Fig.2. Desi (left) and kabuli (right) type chickpea

3.1 Vegetative Growth Stages

VE Seedling emergence

V1 The first multifoliate leaf unfolded from the stem

V2 The second multifoliate leaf unfolded from the stem

V3 The third multifoliate leaf unfolded from the stem

V4 The fourth multifoliate leaf unfolded from the stem

Vn The nth multifoliate leaf unfolded from the stem

Seed germination: Chickpea seeds have a seed coat, two cotyledons and an embryo (Fig. 3a). The seed coat consists of two layers, the outer testa and the inner tegmen and a hilum. The hilum is the point of attachment of the seed to the pod. There is a minute opening above the hilum called the micropyle and a ridge formed by the funicle called the raphe. The embryo consists of an axis and two fleshy cotyledons (Figs. 3 b, c, d). The pointed end of the axis is the radicle and the feathery end is the plumule. Chickpea seeds germinate under optimum temperature (28 - 33°C) and moisture conditions in about 5 - 6 days. The radicle emerges first, followed by the plumule (Figs. 3 e, f, g, h, i). The portion of the axis above the cotyledon is called the epicotyl, which elongates and pushes the plumule upward. The growth of the plumule produces an erect shoot and the leaves, while the radicle grows to produce the roots. The first true leaf has 2 or 3 pairs of leaflets plus a terminal one (Fig. 3j). The plumular shoot and lateral branches grow continuously and develop into a plant (Cubero, 1987).

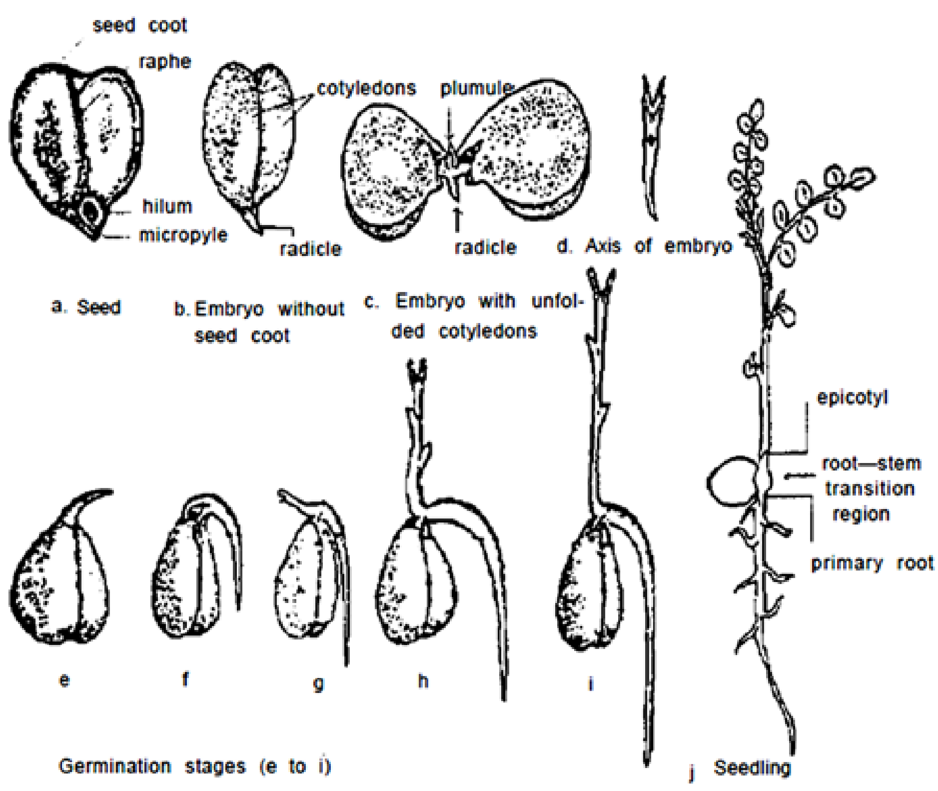

Fig. 3. Seed germination stages of chickpea.

Roots: Chickpea plants have a strong taproot system with 3 - 4 rows of lateral roots. The parenchymatous tissues of the root are rich in starch. All the peripheral tissues disappear at plant maturity and are substituted by a layer of cork (Cubero, 1987). The roots grow 1.5 - 2.0 m deep. Chickpea roots bear *Rhizobium* nodules (Fig. 4). They are of the carotenoid type, branched with laterally flattened ramifications, sometimes forming a fanlike lobe (Corby, 1981).

Stem: The chickpea stem is erect, branched, viscous, hairy, terete, herbaceous, green and solid. The branches are usually quadrangular, ribbed and green. There are primary, secondary and tertiary branches.

Primary branches: The primary branches arise from the ground level as they develop from the plumular shoot as well as the lateral branches of the seedling. They are thick, strong and woody and may range from one to eight in number. The primary branches form an angle with a vertical axis, ranging from almost a right angle (prostrate habit) to an acute angle (erect). Generally stems are incurved at the top, forming a spreading canopy.

Secondary branches: The secondary branches develop at the buds located on the primary branches. They are less vigorous than the primary branches. Their number ranges from 2 to 12. The number of secondary branches determines the total number of leaves and hence the total photosynthetic area.

Tertiary branches: The tertiary branches arise from the secondary branches.

Leaves: The leaves are pubescent. The chickpea leaves are petiolate, compound and uni-imparipinnate (pseudo-imparipinnate) (Fig. 4a). Some lines have simple leaves. The rachis is 3 - 7 cm long with grooves on upper surface. Each rachis supports 10 - 15 leaflets, each with a small pedicel. The leaflets do not end at the true terminal position (the central vein continuing the rachis), but at the sub-terminal position (the central vein oblique to the rachis). This indicates the presence of two terminal leaflet buds, one of them being aborted or transformed into a foliar shoot, which sometimes is quite large (Cubero, 1987). The leaflets are 8 - 17 mm long and 5 - 14 mm wide, opposite or alternate with a terminal leaflet. They are serrated, the teeth covering about two-thirds of the foliar blade. The shape of the leaflets is obovate to elliptical with the basal and top portions cuneate or rounded.

Fig. 4 a. Chickpea leaves (normal leaf – left, multipinnate - middle, and simple - right).

Stipules: The stipules are ovate to triangular in shape and serrated (2 - 6 teeth). They are 3 - 5 mm long and 2 - 4 mm wide. The longest margin is toothed and the smaller one entire (Cubero, 1987).

Pubescence: The external surface of the chickpea plant, except the corolla, is densely covered with glandular and nonglandular hairs. The hairs vary in form and dimension: short stalked, multicellular stalked (both glandular and nonglandular) and unicellular. Some genotypes, however, do not possess any hair.

3.2 Reproductive Growth Stages

Solitary flowers are borne in an axillary raceme. Sometimes there are 2 or 3 flowers on the same node. Such flowers possess both a peduncle and a pedicel (Fig. 4b). The racemose peduncle is 6 - 30 mm in length. At flowering, the floral and racemal portions of the peduncle form a straight line, giving an impression that the flowers are placed on the leafy axil by a single peduncle. After fecundation, the raceme is incurved. The bracts are 1 - 5 mm in length.

The self-pollinated plant produces 1–2 flowers at the tip of axillary branches. Pods may contain up to 3 seeds and are oval in shape. At maturity, the plants and pods turn yellow to tan. Different reproductive growth stages are as follows:

- R1 Early bloom, one open flower on the plant
- R2 Full bloom, most flowers are open
- R3 Early pod visible
- R4 Flat pod, pod has reached its full size and is largely flat.
- R5 Early seed, seed in any single pod fills the pod cavity

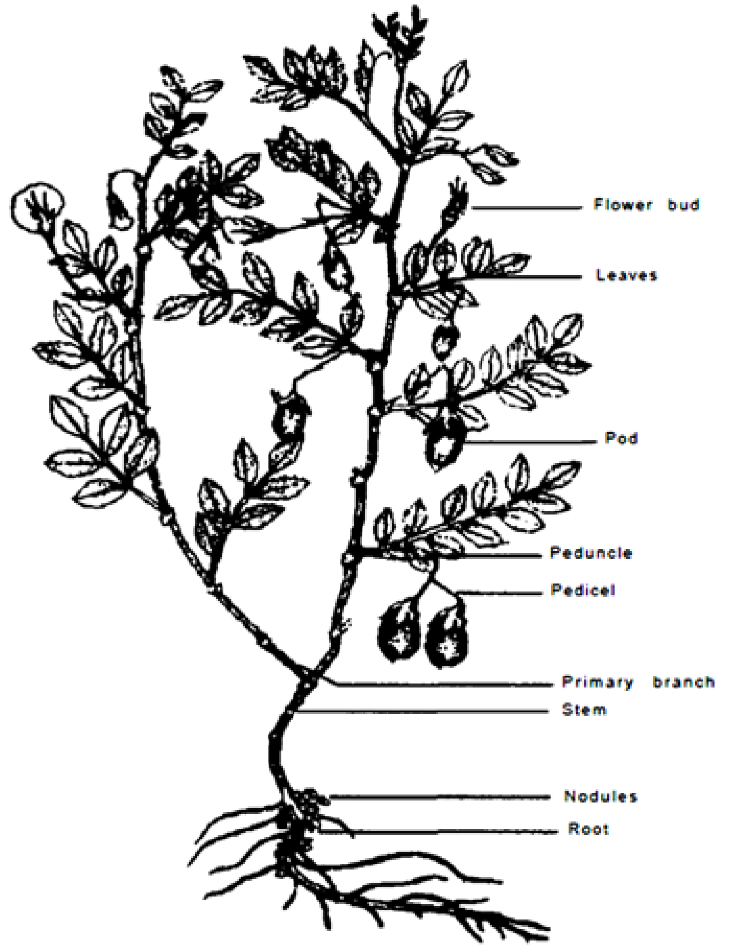

Fig. 4b. A typical Chickpea plant.

- R6 All seeds fill the pod cavity which is rounded
- R7 The leaves start yellowing and 50% of the pods have turned yellow
- R8 90% of pods on the plant are golden-brown.

3.3 Floral Biology

Chickpea flowers are complete, bisexual and have a papilionaceous corolla. They are white, pink, purple, or blue in color (Fig. 4c). In colored flowers, the peduncle may be of different color, the floral part purplish and the racemal green. The axillary inflorescence is shorter than the subtending leaf (Cubero, 1987). The calyx consists of five sepals and the corolla is comprised of standard two wings and two lower petals that lie inside the wings, which are united at the lower margins to form a keel. There are 10 stamens, which surround the pistil. The anthers open lengthwise and shed the pollen directly onto the stigma.


Pink flowers.


White flowers.

Fig. 4c. Variation in flower color in Chickpea.

Calyx: The calyx is dorsally gibbous at the base. There are five sepals with deep lanceolate teeth (Fig. 5a). The teeth are longer (5-6 mm) than the tube (3-4 mm) and have prominent midribs. The five sepals are sub-equal. The two dorsal (vexillar) sepals are closer to each other than they are to the two lateral ones in the ventral position. The fifth calyx tooth is separate from the others. The peduncles and the calyx are glabrous. The calyx tube is oblique.

Corolla: Chickpea flowers have five petals which are generally celeste and purplish red or light pink in color. The petals are polypetalous i.e., consisting of standard (vexillum), wings and keel (Fig. 5b). The vexillum is obovate, 8-11 mm long, 7-10 mm wide and either glabrous or pubescent with no external glandular hairs. Wings are obovate with short pedicels (nails). They are 6-9 mm long and 4 mm wide with an auriculate base. The auricula is over the pedicel and forms a pocket in the basal region, which is covered by the vexillum. The keel is 6-8 mm long and rhomboid with a 2-3 mm long pedicel. Two-thirds of the frontal side of its ventral face is adnate. The wings do not show concrescence with the keel.

Androecium: There are 10 stamens in diadelphous (9+1) condition (Fig. 5 d-e). The filaments of nine of the stamens are fused, forming an androecial sheath, the tenth stamen is free. The staminal column is persistent. The fused part of the filament is 4-5 mm long and the free part 2-3 mm, upturned and dilated at the top. The apex of the sheath is oblique. The stamens facing the petals are a little longer than the others. The anthers of these stamens are bicelled, basifixed and round. The other anthers are dorsifixed, ovate and longer than the basifixed ones at flowering. The anthers burst longitudinally. The pollen grains are orange in colour.

Gynoecium: The ovary is monocarpellary, unilocular and superior, with marginal placentation. It is ovate with a pubescent (glandular hairs predominate) surface. The ovary is 2-3 mm long and 1-15 mm wide. There are 1-3 ovules, rarely 4 in each flower. The style is 3-4 mm long, linear, upturned and glabrous, except at the bottom. The stigma is globose and capitate (Fig 5c). Sometimes it may be of the same size as the style (Cubero, 1987).

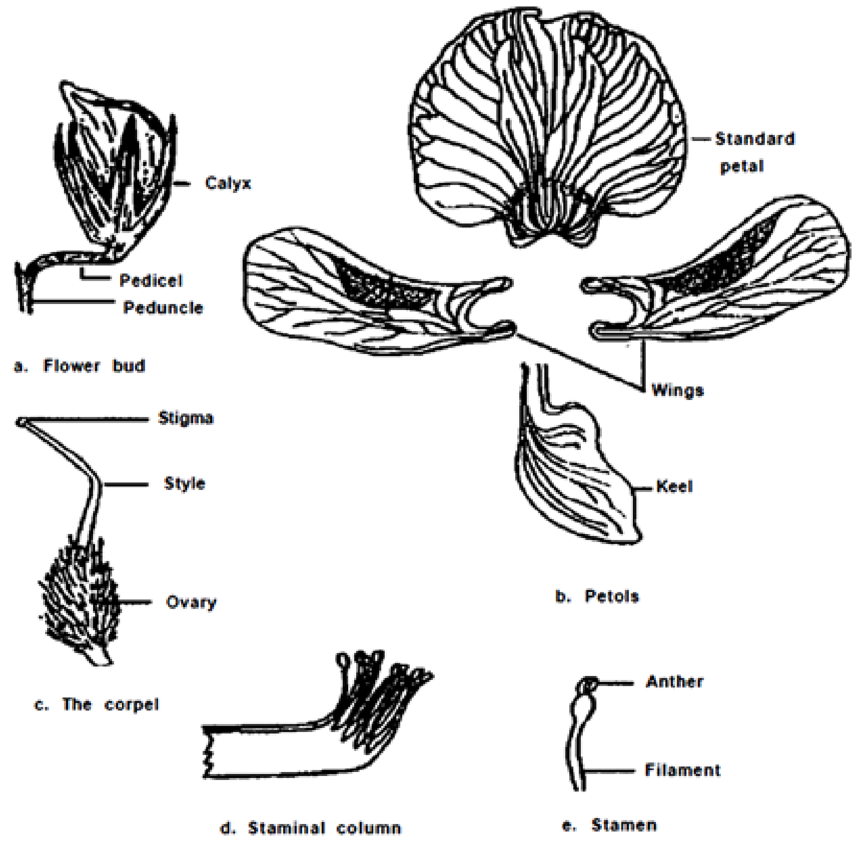

Fig. 5 (a-e): Parts of Chickpea flower

Developmental stages of the flower bud and the flower

Eshel (1968) identified five stages of development of the flower bud and the flower in chickpea.

Closed bud: At this stage, the stigma is immature and the anthers are still at the base of the bud.

Hooded bud: The corolla has elongated and the anthers are about half the height of the style. The stigma is receptive. Emasculation is done at this stage for cross pollination.

Half-open flower: At this stage, the anthers attain the same height as the stigma and the pollen matures just before the dehiscence of the anthers. Self-pollination takes place at this stage while the keel petal remains closed, preventing the entry of foreign pollen. Pollens are collected at this stage for crossing.

Fully open flower: The anthers become shriveled, while the standard and wing petals are fully expanded. Fertilization takes place 24 h after pollination.

Fading flower: This is the post fertilization stage during which the ovary begins to elongate. Chickpea is a highly self-pollinated crop and hence, selfing is not required to maintain the genetic purity of the seed.

Anthesis: Anther dehiscence takes place inside the bud one day before the opening of the flower. When pollen is first liberated, the stigma is still above and free from the base of the anthers. The filament gradually elongates to carry the anthers above the stigma. This process is completed before the flower opens, thus facilitating self-pollination. Anthesis in chickpea takes place throughout the day. Under favorable conditions, the time taken from fertilization to the first appearance of pod (pod set) is about 6 days.

Pod and seed development

Pod formation begins 5-6 days after fertilization. The pod is typically inflated, ending in a mucro and sometimes looking like a thorn. The number of pods plant-1 varies between 30-150, depending on the environmental conditions and the genotype. The podwall is 0.3 mm thick with three layers: exocarp, mesocarp and the endocarp. The exocarp is hairy and glandular. The mesocarp has 6-8 layers of parenchyma. The endocarp consists of 3-4 cell layers with fibers in its outermost region and 5-6 layers of parenchyma (Cubero, 1987).

Pod size ranges from 15 to 30 mm in length and 2-15 mm in width. Depending on the basal and apical zones and the dorsal and ventral regions, pod shape varies from rhomboid, oblong to ovate. The number of seeds pod-1 ranges from 1-2, with a maximum of 3 seeds. The seeds are ramhead or owl's-head shaped and the surface may be smooth or wrinkled. The two cotyledons are separated by a groove in highly wrinkled seeds. The beak above the micropyle is produced by the tip of the radicle. The shape of the cotyledons varies from semispherical to oviform. The length of the seed ranges from 4-12 mm and its width from 4-8 mm. The seed mass varies from 0.10 to 0.75 g seed-1. The seed color ranges from whitish (even chalky) and cream to deep black. Seeds of many other colors such as red, orange, brown, green and yellow may also be found. The cotyledons are cream, green, or orange colored (Cubero, 1987).

After pod set, the pod wall grows rapidly for the first 10 to 15 days, while seed growth occurs later. Soon after development of pods and seed filling, senescence of subtending leaves begins. If there is plenty of soil moisture, flowering and podding continue on the upper nodes. Chickpea can tolerate high temperatures if there is adequate soil moisture. Chickpea is ready to harvest when 90% of the stems and the pods turn light golden yellow.

3.4 Pollination and Fertilization

The natural rate of pod-setting in chickpea lies between 18 and 59%. Singh and Auckland (1975) reported 24% pod-setting when artificial pollination was carried out on the same day of emasculation and 15% pod-setting when it was done one day after emasculation. Low seed-setting in chickpea is mainly due to high humidity and cloudy weather. However, van der Maesen (1972) did not find pollination or fertilization to be affected by relative humidity per se. He suggested that suboptimum soil moisture and relative humidity affect the seed-setting.

3.5 Seed Dispersal

Wild *Cicer* species shed the dehiscent pods, which drop to the ground where they burst and disperse the seeds (Ladizinsky and Adler, 1976a). In cultivated chickpea, this feature has been suppressed through breeding. The pods are retained on the plant and dehiscence has been reduced considerably (Singh and Bejiga, 1991). Cultivated chickpeas do not exhibit seed dormancy, but some wild *Cicer* species do (Singh and Ocampo, 1997).

3.6 Mating Systems

Since chickpea is predominantly a self-pollinated crop, the presence of linkage blocks and inverse relations among the correlated characters are quite common. Under such circumstances, the biparental mating in an appropriate segregating population is effective in breaking larger linkage blocks and provides greater opportunity for recombination than selfing (Gill, 1987). It is a useful system for rapid generation of variability and can be applied where lack of desired variation is the immediate bottleneck in the breeding programs.

There is a need to break unfavorable linkages to make selection more effective and useful. In self-pollinated crops such as chickpea, the conventional methods of mass selection do not provide any opportunity for continued reshuffling of genes. Therefore, any unfavorable associations observed in early segregating generations are liable to persist through the filial generations. However, breeders can alter such associations by resorting to biparental mating in the segregating populations. Such approaches have been tried and positive results have been reported in wheat and safflower (Nanda *et al.*, 1990; Parameshwarappa *et al.*, 1997).

3.7 Methods of Reproductive Isolation

Chickpea being a self-pollinated crop, has a very low outcrossing percentage (0-1%). In India an isolation distance of 10m for foundation seed and 5 m for certified seed has been recommended. This isolation helps in maintaining genetic and physical purity of the seeds during seed production.

4. CROSSABILITY BETWEEN *CICER SPP*. AND HYBRIDIZATION

4.1 Interspecific Crosses

Wild relatives of chickpea are important sources of resistance to biotic and abiotic constraints (Fig. 6). Wild *Cicer* species such as *C. bijugum, C. reticulatum, C. judaicum, C. pinnatifidium, C. microphyllum* and *C. cuneatum* have shown high levels of resistance to pod borer, *Helicoverpa armigera* (Sharma *et al*., 2005, 2006). Accessions belonging to *C. bijugum, C. pinnatifidum* and *C. echinospermum* have also shown resistance to the bruchid, *Callosobruchus chinensis*. Many of these accessions can be exploited to develop insect-resistant cultivars to reduce overdependence on pesticides. There is some information on the nature of barriers to crossability in the annual wild *Cicer* species and methods are available to overcome these barriers (Mallikarjuna, 1998; Mallikarjuna *et al*., 2005). A large number of *Cicer* species are perennials, however, none of these have been exploited for chickpea improvement. Crossability barriers between chickpea and perennial *Cicer* species are post-zygotic (Mallikarjuna 2001; Babb and Muehlbauer, 2005) and there is ample scope to use them in chickpea improvement. Based on the studies on crossability and fertility of hybrids in the interspecific crosses among seven annual species of chickpea, Ladizinsky and Adler (1976a) have placed seven annual *Cicer* species (except *C. chorassanicum* and *C. yamashitae*) into the following three crossability groups. Interspecies hybridization is possible within the group, but not between the groups.

Cicer microphyllum

Cicer reticulatum

Cicer bijugum

Cicer judaicum

Fig. 6. Wild relatives of chickpea with resistance to pod borer, *Helicoverpa armigera*.

Group I: It is the most important group among the annual *Cicer* species and includes the cultivated species, *C. arietinum* along with its close wild relatives, *C. reticulatum* and *C. echinospermum*. The regular formation of 8 bivalents during meiosis, completely fertile F1 hybrids and normal segregation of F_2 progenies in *C. arietinum* x *C. reticulatum* crosses shows high cross compatibility between the two species (Pundir and van der Maesen, 1983; van der Maesen, 1980). High crossability and free gene exchange between the two species as compared to the other annual species supports the idea of *C. reticulatum* being the possible wild progenitor of the cultivated chickpea.

Interspecific hybrids between *C. arietinum* and *C. echinospermum* develop normally, but exhibit high degree of sterility. The difference in pollen fertility among the reciprocal crosses between *C. arietinum* x *C. echinospermum* indicated presence of maternal effects (Pundir and Mengesha, 1995; Singh and Ocampo, 1993), suggesting that the cultivated species should always be used as the female parent for interspecific hybridization. Low success rate of crosses has been observed when *C. echinospermum* was used as the female parent. Formation of a quadrivalent during meiosis in some crosses of *C. arietinum* x *C. echinospermum* indicated presence of a reciprocal translocation, while paracentric inversions were seen in some other crosses, leading to formation of unbalanced gametes (Ladizinsky and Adler, 1976b). The F2 progenies of these two species, despite their similar chromosome number and almost regular meiosis in F1, exhibited varying degrees of sterility (0 – 100%) (Pundir and Mengesha, 1995) and low pod set (Verma *et al.*, 1990). The sterility of the hybrid may be due to reciprocal translocation or cryptic structural changes or the involvement of genetic factors (Ladizinsky and Adler, 1976b).

Group II: It includes the annual species *C. bijugum*, *C. judaicum* and *C. pinnatifidum*. These species show close homology of chromosomes, but no seeds were produced in any of the F1 hybrid combinations because of unique post zygotic reproductive barrier. Crosses between the three annual wild species and *C. arietinum* yielded no viable seeds. By attempting multiple numbers of pollinations, interspecific hybrids have been produced between *C. arietinum* and *C. judaicum*, *C. pinnatifidum* and *C. bijugum*. The success in producing interspecific hybrids depends upon the number of pollinations attempted and the specific cultivar wild species combination (Verma *et al.*, 1990). The accession GLG 84038 of cultivated species exhibited the highest level of crossability with the wild species, suggesting that genetic variability within the cultivated species plays an important role in crossability with the wild species (Verma *et al.*, 1990, 1995). Some successful hybrids between *C. arietinum* x *C. bijugum* have also been reported and their hybridity confirmed by molecular analysis (Lulsdorf *et al.*, 2005). A very low level of seed set has been reported in the cross *C. arietinum* x *C. pinnatifidum* (Badami *et al.*, 1997). Ahmad *et al.* (1987) reported interspecific hybrids between *C. judaicum* x *C. chorassanicum*, which were sterile with a pollen fertility of 4.8%. Ahmad *et al.* (1988) also reported an interspecific hybrid between *C. chorassanicum* x *C. pinnatifidum* and placed *C. chorassanicum* along with group II species and *C. yamashitae* in a separate group.

Group III: This includes only one annual species *C. cuneatum*, which originated in Ethiopia. It exhibits cross incompatibility with group I and group II species and thus, is considered as the most distant relative of the cultivated species. *Cicer cuneatum* is the only annual *Cicer* species having climbing growth habit.

Utilization of *C. reticulatum* accession, ILWC 119 in crossing program has resulted in the development of two cyst nematode-resistant chickpea germplasm lines ILC 10765 and ILC 10766 (Malhotra *et al.*, 2002). Promising high yielding lines with good agronomic and seed traits such as early flowering and high 100-seed weight have also been obtained from crosses involving *C. reticulatum* and *C. echinospermum* with cultivated chickpea (Singh *et al.*, 1984; Singh and Ocampo, 1997; Malhotra *et al.*, 2003; Singh *et al.*, 2005; Upadhyaya, 2008). High yielding cold tolerant lines with high biomass have also been obtained from *C. arietinum* x *C. echinospermum* crosses (ICARDA, 1995). From *C. arietinum* x *C. judaicum* cross, a pre-breeding line IPC 71 having high number of primary branches, more pods per plant and green seeds has been developed for use in chickpea improvement programs (Chaturvedi and Nadarajan, 2010).

4.2 Wild Relatives in India

There are no wild relatives of chickpea in India, except *C. microphyllum* belonging to the tertiary genepool. Hence, there are no concerns of geneflow to the wild relatives in India. Wild relatives of chickpea are classified into different genepools based on their crossability with the cultivated chickpea. There are many wild species, which are held in the genebanks at ICRISAT and NBPGR, which are being utilized for the improvement of cultivated species. It is important to select appropriate parents for exploitation of wild relatives of crops for crop improvement. This is particularly true in interspecific hybridization where the aim is to seek transfer of small fragments of genome of the donor parent into agronomically desirable cultivars.

5. ECOLOGICAL INTERACTIONS

5.1 Outcrossing and Gene Flow

Chickpea is a predominantly self-pollinated crop. Cross pollination has been reported to the extent of 0-1% (Smithson *et. al.*; 1985; Singh, 1987). Gowda (1981) estimated that there is 1.92% cross pollination in chickpea, which is quite low.

5.2 Volunteers and Weediness

Chickpeas are not known to occur in the wild, but volunteer plants can appear as weeds in subsequent crop. Cultivated chickpeas cannot colonize successfully without human intervention. Cultivated chickpeas do not compete with other plant species in the wild, particularly weeds (Muehlbauer, 1993). However, some wild species occur in weedy or disturbed habitats, such as fallows and roadsides (*C. reticulatum* and *C. bijugum*), but these species are not present in India and there is no chance of any wild species becoming a weed as a result of geneflow, which may confer adaptive advantage against abiotic stresses.

6. HUMAN HEALTH CONSIDERATIONS

Chickpea is a remarkable food in terms of antioxidant composition. While containing small but valuable amounts of conventional antioxidants such as Vitamin C, Vitamin E and Beta-Carotene, chickpea also contains antioxidant phytonutrients. These phytonutrients include the flavonoids such as quercetin, kaempferol and myricetin (usually found in the outer layer of beans) and the phenolic acids such as ferulic acid, chlorogenic acid, caffeic acid and vanillic acid (usually found in the interior portion of bean). Depending on the type of pea and color/thickness of the outer layer, chickpea also contains significant amounts of anthocyanins such as delphinidin, cyanidin and petunidin. The mineral manganese, a key antioxidant in the energy-producing mitochondria found inside most cells, is also present in sufficient amounts. Strong vitamin and mineral composition coupled with strong anti oxidant composition can stabilize digestive impact on blood sugar and therefore chickpea help in improving blood sugar regulation.

7. CHICKPEA CULTIVATION IN INDIA

As chickpea has a deep tap root, which enhances its capacity to withstand drought conditions, it is usually suited to areas having relatively cooler climatic conditions and low rainfall. It yields best when grown on sandy loam soils having an appropriate drainage system, as it is very sensitive to excess water. Chickpea production is also affected by excessive cold and heat. In India, chickpea is a winter season crop, but severe cold and frost are injurious. Frost at the time of flowering results in failure of flowers to develop into seeds or kills the seeds inside the pod. It is generally grown under rainfed conditions, but gives good returns under irrigated conditions. Excessive rains soon after sowing or at flowering and fruiting or hailstorms at ripening cause heavy crop loss. It is best suited to areas having moderate rainfall (60 - 90 cm per annum). Chickpea is sown between September to November in India. The maturity of Desi types chickpea is 95 - 105 days and of the Kabuli types 100 - 110 days. In India, it is harvested in February, March and April depending on the region where it is grown. Chickpea is often cultivated as a sole crop, but at times it is also grown in rotation with other crops such as sorghum, pearl millet, wheat and coriander. The area under chickpea cultivation in India has increased from 7.49 ha in 2007 to 8.32 ha in 2012 and the total production has increased from 6.33 million tonnes in 2007 to 7.70 million tonnes in 2012 (FAOSTAT, 2012).

Chickpea is grown on a wide range of soils in India. In the North, it is generally grown on moderately heavy sandy loam soils. In Maharashtra and Deccan plateau, it is grown on deep black Vertisols. Light soils, mostly sandy loams are preferred in Punjab, Uttar Pradesh, Haryana and Rajasthan. Sandy loam to clay loam is considered most suitable. Well drained and not too heavy soils are best suited for growing chickpea. On dry and light soils, the plants remain short, while on heavy soils having high water retention capacity, the vegetative growth is abundant, in which light becomes a limiting factor and the fruiting is reduced. The soil should be free from excessive soluble salts and near neutral in reaction. However, it is not suited to soils having a pH higher than 8.5.

8. AGROCLIMATIC ZONES AND VARIETAL TESTING SYSTEM

The prevalent cropping systems in the Indian subcontinent are the outcome of technological innovations, household needs, reflection of government policies and availability of production inputs, market forces and socio-economic compulsions. Chickpea is grown in a variety of cropping systems such as monocropping, double cropping, relay cropping and mixed cropping. In central and peninsular India, where rainfall is not adequate to grow two crops in a year, monocropping is practiced. In these areas, chickpea is rotated with sorghum in a 2 year cycle. Monocropping is also practiced in flood and *Tal* affected areas (diara land) of eastern Uttar Pradesh, Bihar, West Bengal and Orissa, where chickpea is planted after receding of flood waters. Double cropping is practiced in areas having assured rainfall (eastern Uttar Pradesh, Bihar and West Bengal) or under irrigation (Punjab, Haryana and western Uttar Pradesh). In these areas, chickpea is grown after kharif maize, sorghum, pearl millet, short-duration cotton and early rice. After the harvest of rice, the use of low-energy tillage methods confines the cultivation to a shallow depth, giving rise to a compact layer, which may affect root growth, particularly in clay soils. However, the major production constraints are non-availability of cold-tolerant varieties, pod borer, *Helicoverpa armigera* damage, *Fusarium wilt, Ascochyta blight* and *Botrytis grey* mould (BGM), besides poor soil tilth and nodulation. There are several production zones, each with its own agro-climatic conditions and production constraints, as indicated below:

- Alluvial soils of Indo-Gangetic Plains (IGP)
- Rice fallows of north-eastern India
- Sandy soils of southern Punjab, Haryana and northern Rajasthan
- Black soils of central India
- Black soils of peninsular India.

For the purpose of varietal release, elite chickpea breeding lines are evaluated to assess their performance with respect to grain yield, disease resistance and their suitability for cultivation in specific zone(s). Testing centres and growing areas have been dividied into five zones (Fig 7), namely-

1. North Hill Zone (NHZ) comprising Uttarakhand, Tripura, Nagaland and Assam
2. North East Plain Zone (NEPZ) comprising central and eastern Uttar Pradesh, Bihar, Jharkhand and parts of West Bengal
3. North West Plain Zone (NWPZ) comprising Delhi, Haryana, Rajasthan, Punjab, western Uttar Pradesh and *tarai* region of Uttarakhand
4. Central Zone (CZ) comprising Madhya Pradesh, central and southern Chattisgarh, Gujrat and Maharashtra
5. South Zone (SZ) comprising Orissa, Telangana, Andhra Pradesh, Karnataka and Tamil Nadu

AICRP CHICKPEA CENTRES

Figure 7: Zonalization and testing centers of Chickpea.

9. INSECT PESTS, DISEASES AND WEEDS

Chickpea being a rich source of proteins, is prone to damage by insect-pests and diseases. In general, root diseases (*Fusarium wilt*, collar rot and dry root rot) are more prevalent in central and peninsular India, whereas foliar diseases (*Ascochyta blight* and *Botrytis grey* mould) are important in northern, north - western and eastern India. Among the insect pests, pod borer, *H. armigera* is the most severe yield reducing factor in the field, while the bruchids, *C. chinensis* cause severe damage in storage. Various aspects of insect pest, diseases and weed management in chickpea have been discussed by Chen *et al.* (2011).

9.1 Diseases of Chickpea

i. ***Fusarium wilt*** (*Fusarium oxysporum f. sp ciceris*): It is a major constraint to chickpea production worldwide and has been reported from 32 countries. It is estimated to cause 10 - 15% yield loss annually. It is a seed and soil born disease and can affect the crop at any growth stage. It can survive in the soil in the absence of the host for at least 6 years. Affected seedlings first show drooping of the leaves and then collapse (Fig. 8). The roots look healthy, but when split vertically, the vascular tissues show brown to black discoloration. There are six races of *Fusarium wilt* in India, which can be identified by using different chickpea differentials.

ii. **Collar rot** (*Sclerotium rolfsii*): It is becoming a serious problem in central and peninsular India. High soil moisture, presence of un-decomposed organic matter on the soil surface, low soil pH and warm temperature (25 to 30^0 C) favor the disease. Collar rot is generally seen at the seedling stage. Seedlings show rotting symptoms at the collar region and downwards (Fig. 9). White mycelial strands with minute mustard seed-sized sclerotial bodies are seen growing over the affected tissue. The affected seedlings turn yellow and wilt.

Figure 8. Symptoms of *Fusarium wilt*.

Fig. 9. Symptoms of collar rot.

iii. **Dry root rot** (*Rhizoctonia bataticola*): It is an emerging disease of chickpea, particularly in central and southern India. It generally appears at the flowering and podding stages. It is favoured by moisture stress and when the crop is exposed to temperatures above 30^0 C. The whole plant dries up and turns straw-colored (Fig. 10). Roots become black and brittle and have a few lateral roots or none at all. Dark, minute sclerotial bodies can be seen on the roots or inside the wood.

Fig 10. Symptoms of dry root rot.

iv. ***Ascochyta blight*** (*Ascochyta rabiei*): It is a potentially devastating foliar disease in northern and north-western India, where relatively low temperatures along with wet weather lead to disease outbreak. Winter rains result in increased incidence of *Ascochyta blight*. Disease symptoms usually appear during the flowering and podding stages in patches in the field (Fig. 11). Typical circular spots appear on leaves and the pods, elongated lesions on stem and deep cankerous lesions on seeds.

Fig. 11. Symptoms of *Ascochyta blight*.

v. ***Botrytis grey*** **mould** (*Botrytis cinerea*): It is an important foliar disease in North-Eastern regions of India. The disease appears on all aerial parts of the plant, the growing tips and flowers being the most vulnerable. Water soaked lesions and rotting of terminal buds with moldy growth are the main foliage symptoms (Fig. 12). The disease can cause flower drop, resulting in poor pod setting and extension of the crop duration.

Fig 12. Symptoms of *Botrytis grey* mould.

9.2 Insect Pests of Chickpea

i. Pod borer (*Helicoverpa armigera*)**:** It is the most devastating pest of chickpea. It damages almost all stages of the crop, but damage at the flowering and podding stages can result in complete crop loss (Fig. 13). On an average, it causes nearly 20 - 30% yield losses in India annually (Sharma, 2005; Chen *et al.*, 2011). The eggs (1 mm diameter) are laid singly on the leaflets, flowers, immature pods and the stem. Larvae can be green, brown, yellow, or pink, but are usually striped, irrespective of their color. Larvae feed on the leaves during the vegetative stage and on flowers and pods during the reproductive phase. It damages both vegetative and reproductive stages in peninsular India, but mostly flowers and pods in North India. The third- to fifth-instar larvae feed on the developing seed after making a hole in the pods.

Fig. 13. Pod borer, *Helicoverpa armigera* damage in chickpea.

ii. Beet armyworm (*Spodoptera exigua)*: The beet armyworm, *Spodoptera exigua* is a serious pest of chickpea in some regions of southern India. It causes severe damage in chickpea, cotton, peanut, safflower, sorghum, soybean, sugarbeet, and tobacco (Chen *et al.*, 2011). The young larvae of *S. exigua* initially feed gregariously on chickpea foliage. As the larvae mature, they become solitary and feed on foliage making large irregular holes (Fig. 14). As a leaf feeder, beet armyworm consumes much more chickpea tissue than *H. armigera*. The *S. exigua* females lay eggs in clusters of 50 to 150 eggs. A female lays 300 to 600 eggs on the lower surface of the leaves, near the blossoms and the terminal branches. The eggs are greenish white in color and covered with a layer of whitish scales, which gives the egg mass a fuzzy or cottony appearance. Eggs hatch in 2 to 3 days during warm weather.

There are five instars, although additional instars have also been reported. The larvae are pale green or yellow in color during the first and second instars, but acquire pale stripes during the third-instar. During the fourth-instar, the larvae become darker dorsally and possess a dark lateral stripe. Fifth-instar larvae are quite variable in appearance and tend to be green dorsally with pink or yellow color ventrally and a white stripe laterally. Sometimes, the larvae assume a dark color. Pupation occurs in the soil. The forewings are mottled grey and brown and have irregular banding pattern and a light bean-shaped spot. The hindwings are of uniform grey or white color and trimmed with a dark line at the margins. Oviposition extends over a 3 to 7 day period and the adults live for 9 to 10 days. Seasonal activity varies considerably according to climate. The life cycle can be completed within 24 days. There are several generations in a year, which vary across regions, depending upon the climate.

Fig. 14. Beet armyworm, *Spodoptera exugua* damage in chickpea.

iii. Black aphid, (*Aphis craccivora)*: The black aphid, *Aphis craccivora* is an important pest of chickpea. *Aphis craccivora* is also important as a vector of chickpea stunt disease. It is widely distributed in the tropics, where it is one of the most common aphid species. It has an extensive host range and damages several grain legumes including chickpea, lentil, cowpea, groundnut, alfalfa and other legumes (Chen *et al.*, 2011). Both nymphs and adults suck the plant sap from the tender leaves, stems and pods and mostly colonize the young leaves and growing points, which become characteristically deformed (Fig. 15). Yield may be drastically reduced and if infestations are early and severe, plants can be killed completely. In many areas, *A. craccivora* is more important as a vector of viruses than as a direct plant feeder. While feeding, the aphid produces considerable amount of honeydew upon which sooty mould grows.

Fig. 15 Back aphid (*Aphis craccivora*) infesting chickpea.

The life cycle of *A. craccivora* passes through nymph to adult stage, which is completed in 8 to 10 days. The aphids are active throughout the year and a female can produce over 100 nymphs in 15 days and there are several generations in the tropics.

iv. Termites (***Microtermes spp***. and ***Odontotermes spp***.)

Termites may be a problem in some fields, as these can infest chickpea plants at all stages of crop growth. The initial damage to the seedlings can cause substantial seedling mortality (Fig. 16). The roots and stems are tunnelled and one can see termites inside the stem. *Odontotermes spp*. cover themselves with earthen galleries under which they feed (Chen *et al*., 2011).

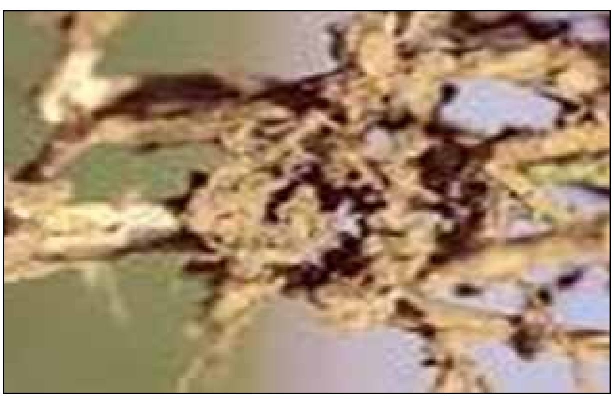

Fig. 16. Termite, Odontotermes spp. damage in chickpea.

v. Cutworms (*Agrotis spp*.): This is generally a pest of minor importance, but may reduce plant stand in case of severe infestation. Gray-black larvae hide beneath the soil surface during the day and become active at night. They cut the seedlings at or below ground level (Fig. 17).

Fig. 17. Cut worm: plant damaged by cutworm (left) and moth of cutworm (right).

vi. Bruchids, (*Callosobruchus spp)*.: Bruchids, *chinensis* and *C. maculatus* are the most important pests of grain legumes in storage, including chickpea and lentil. Bruchid infestation commences in the field even before the crop harvest and then they multiply quite fast in storage, resulting in heavy losses.

Females of *C. maculatus* and *C. chinensis* lay eggs singly on seeds, which are visible to the naked eye. Bruchids tend to lay eggs singly on a given host and if all the seeds are occupied, then the female starts laying eggs on already egg-laden seeds. The neonate larva bores into the seed beneath the oviposition site and completes its development within a single seed. Damaged seeds are riddled with adult emergence holes (Fig. 18) and are unfit for human or animal consumption. The life cycle of bruchids passes through five larval instars, pre-pupal, pupal and adult stages. The egg incubation period of *C. maculatus* lasts for 3 to 5 days and the combined larval and pupal period lasts for nearly 19 days. Total development is completed in about 24 days. The adults of *C. chinensis* and *C. maculatus* are easily distinguishable with the naked eyes.

Fig. 18. Cut worm: plant damaged by cutworm (left) and moth of cutworm (right).

9.3 Parasitic Weeds

More than 4,000 species of angiosperms are parasitic plants, but only a few of them parasitize cultivated plants and become agricultural weeds. Nevertheless, these weedy parasites pose a tremendous threat to farmers' economy, mainly because they are at present almost uncontrollable (Rubiales, 2003). Most important weeds are the root parasites such as broomrapes (*Orobanche* spp.) that connect to host roots and climbers such as doders (*Cuscuta* spp.) that parasitize the shoots.

10. CHICKPEA IMPROVEMENT OBJECTIVES AND CHALLENGES

The main objectives of chickpea improvement programs are as follows (Yadav *et. al.*, 2006).

1. **Breeding for High Yield:** Chickpea has a very low harvest index due to indeterminate growth habit, photo- and thermo-sensitivity and is characterized by poor partitioning of the photosynthates into the grain. Yield potential can be increased by developing cultivars responsive to fertilizer application and irrigation.
2. **Extended Adaptation in Space and Time:** Breeding cultivars for winter sowing in the Mediterranean and for double cropping in the irrigated areas in the Indian subcontinent will be useful to increase chickpea productivity.
3. **Resistance to Biotic Stress:** Breeding for resistance to diseases and insect pests will help stabilize chickpea production. Major emphasis has been placed on breeding for resistance to Fusarium wilt, Ascochyta blight, *Helicoverpa*, leaf miner and root knot nematodes. Several chickpea varieties with high grain yield and resistance to Fusarium wilt have been released for cultivation in India.
4. **Resistance to Abiotic Dtresses:** Breeding for resistance or tolerance to abiotic stresses is an important objective because these result in instability of grain yield. Major abiotic stresses are heat, drought, salinity, cold and frost. Synchronous flowering, shorter flowering and seed filling period and better dry matter accumulation are important for adaptation to drought and high temperatures.

The first systematic efforts in chickpea breeding started nearly 100 years ago in India, after the establishment of the Imperial (now Indian) Agricultural Research Institute at Pusa, Bihar (now at New Delhi) in 1905.

Over 350 improved varieties of chickpea have been released globally and about half of these have been released in India, which has the largest chickpea breeding program in the world (Gaur *et al.*, 2007). Excellent progress has been made in developing early-maturing cultivars, which can escape terminal drought and heat stress (Gaur *et al.*, 2005). The first landmark variety was ICCV 2, which matures in about 85 days and it is perhaps the world's earliest maturing variety of Kabuli chickpea. It has been instrumental in extending Kabuli chickpea cultivation to short-season environments in India and the neighbouring country, Myanmar. Short-duration varieties cover over 50% of the chickpea area in Myanmar (Than *et al.*, 2007). Several short-duration high yielding varieties of chickpea, both in Desi and Kabuli types, have been developed and released for cultivation in India (Gaur *et al.*, 2005, 2007, 2009). Considerable progress has been made in breeding for super-earliness and two super early Desi chickpea lines, ICCV 96029 and ICCV 96030 mature in 75 to 80 days in southern India (Kumar and Rao, 1996).

11.BIOTECHNOLOGICAL ADVANCES IN CHICKPEA RESEARCH

Significant progress has been made in developing the genomic resources in chickpea (Millan *et al.*, 2010; Nayak *et al.*, 2010; Gujaria *et al.*, 2011; Thudi *et al.*, 2011; Gaur *et al.*, 2012; Jain *et al.*, 2013; Varshney *et al.*, 2013). First chickpea genetic maps were mainly focussed on the location of genomic areas controlling disease resistance and agronomic quality traits. Successful results in marker assisted backcrossing (MABC) for drought tolerance and *Fusarium wilt* have been achieved mainly using STMS makers. Varshney *et al.* (2013) reported the draft genome sequence of ~ 738-Mb, which contains an estimated 28,269 genes. Examination of synteny with other legumes revealed extended (>10 kb) conserved syntenic blocks with *Medicago truncatula*. The draft sequence of Desi type chickpea has also become available (520 Mb assembly, covering 70% of the predicted 740 Mb genome length and more than 80% of the gene space) (Jain *et al.*, 2013). Comparison of phenotypic traits located in genetic maps, expression studies and the complete genome sequence will be useful in the future for chickpea improvement. Some of the marker assisted breeding methods using molecular markers are being integrated into chickpea breeding programmes associated with susceptibility to *H. armigera*, *Fusarium wilt*, *Ascochyta blight* and *Drought* stress.

Efforts have been made to use genetic engineering for introducing cry genes against *H. armigera*. The first successful genetic transformation of Chickpea was reported in 1997 by using the cry1Ac gene (Kar *et al.* 1997). Later, transgenic chickpea expressing Cry1Ac (Sanyal *et al.*, 2005; Mehrotra *et al.*, 2011) and Cry2Aa gene (Acharjee *et al.*, 2010) were also generated. Recently, chickpea lines expressing pyramided Bt genes, cry1Ac and cry1Ab have also been developed. The genetically engineered (GE) Chickpea is in the initial stages of field evaluation in India. Efforts have also been initiated to develop drought tolerant chickpea lines (Bhatnagar-Mathur *et al.*, 2009).

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