CHAPTER 8

Chickpea (*Cicer arietinum* L.)

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1. INTRODUCTION

Chickpea (*Cicer arietinum* L.) also called Bengal gram or Garbanzo, is the largest produced food legume in South Asia and the third largest produced food legume globally, after common bean (*Phaseolus vulgaris* L.) and field pea (*Pisum sativum* L.). Chickpea is grown in more than 50 countries (90% area in Asia, 4.7% in Africa, 3.1% in Oceania, 1.6% in Americas and 0.5% in Europe), but developing countries account for over 95% of its production (FAO, 2011). Over 75% of the chickpea production comes from South Asia, where India is the largest chickpea producing country accounting for 67% of the global chickpea production. The other major chickpea producing countries include Pakistan, Turkey, Australia, Myanmar, Ethiopia, Iran, Mexico and Canada (Figure 1). During the triennium 2006-2009, the global chickpea area was about 11.1 m ha with a production of 9.3 m tons and average yield of nearly 838 kg ha-1 (FAO, 2011).

Chickpea is an important source of protein for millions of people in the developing countries, particularly in South Asia, who are largely vegetarian either by choice or because of economic reasons. In addition to having high protein content (20-22%), chickpea is rich in fiber, minerals (phosphorus, calcium, magnesium, iron and zinc) and ß-carotene. Its lipid fraction is high in unsaturated fatty acids. Nutrition qualities and health benefits of chickpea have been summarized in a recent review by Jukanti *et al.* (2012).

Chickpea plays a significant role in improving soil fertility by fixing the atmospheric nitrogen. Chickpea meets 80% of its nitrogen (N) requirement from symbiotic nitrogen fixation and can fix up to 140 kg N ha^{-1} from air (Saraf *et al.,* 1998). It leaves substantial amount of residual nitrogen for subsequent crops and adds plenty of organic matter to maintain and improve soil health and fertility. Because of its deep tap root system, chickpea can avoid drought conditions by extracting water from deeper layers in the soil profile.

Increasing preference for vegetable protein and interest in consumption of chickpea has increased the global demand for chickpea. Chickpea is imported by over 130 countries (FAO, 2011). Awareness of benefits of chickpea in crop diversification and sustainable agriculture has increased interest of farmers in growing chickpea. Chickpea contributes to over 40% of India's total pulse production and is the most important pulse crop of the country. Despite being the largest global producer of chickpea, India needs to import chickpea to meet domestic demand which is higher than the domestic production. On an average, India has about Rs 440 crores (US$ 97.5 millions) per year on chickpea imports during 2005 to 2008 (FAO, 2011).

Madhya Pradesh is the largest chickpea producing state in India, contributing to 39% of the country's production (Figure 2). The other major chickpea producing states are Rajasthad, Andhra Pradesh and Maharastra etc.

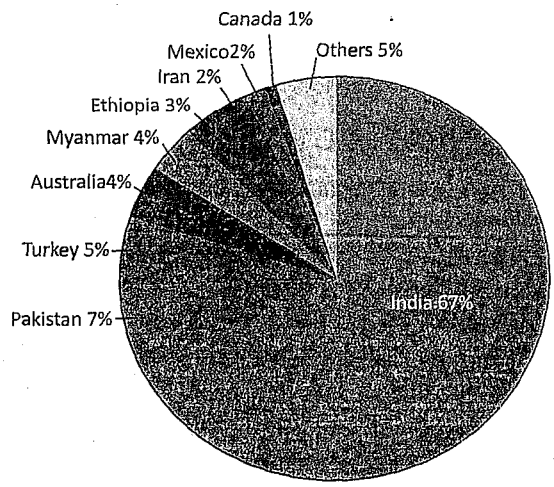

FIGURE 1: Major chickpea producing countries during 2008-09.

During the past four decades, there has been a major shift in chickpea area from the cooler, long-season environments (northern India) to warmer, short-season environments (southern India) (Figure 3). This is mainly due to expansion of irrigated agriculture in northern India leading to replacement of chickpea with wheat and other cash crops. area in northern India (Punjab, Haryana, Uttar Pradesh and Bihar states) declined by 4.4 million ha (from 5.14 to 0.73 million ha), while increased in central and southern India (Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka) by 3.5 million ha. (from 2.05 to 5.56 million ha).

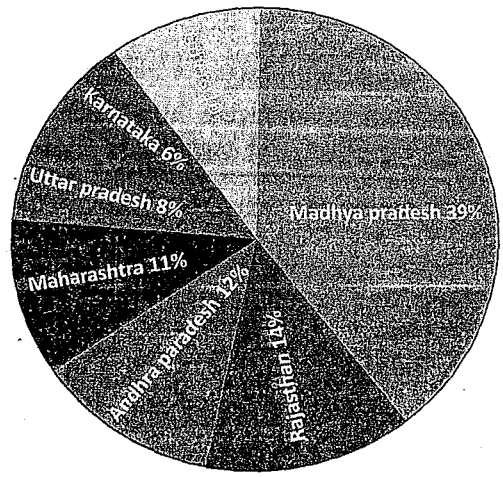

FIGURE 2: Share of different states in chickpea production in India during 2008-09.

During 1964-65 to 2008-09, the chickpea The availability of early maturing and high yielding varieties helped in expansion of area in central and southern India. This major shift in chickpea area has implications on chickpea breeding objectives in India.

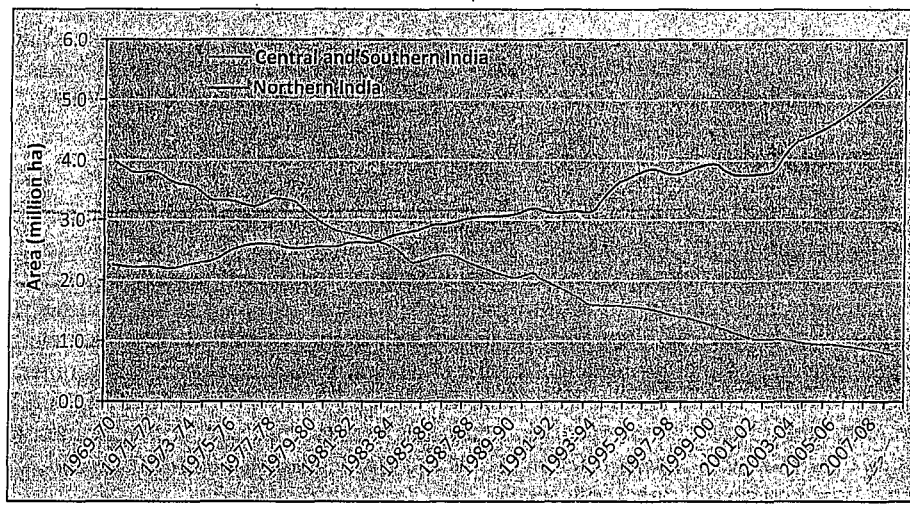

FIGURE 3: Shift in chickpea area from northern India to Central and Southern India.

Year	Area (1000 ha)	Production (1000 t)	Yield (kg/ha)
1999-00	163	95	583
2000-01	201	229	1138
2001-02	285	363	1274
2002-03	390	382	979
2003-04	422	457	1081
2004-05	341	345	1012
2005-06	394	627	1590
2006-07	602	653	1087
2007-08	638	912	1448
2008-09	628	884	1407

2. CENTERS OF ORIGIN

There are different views on the origins of chickpea. De Candolle (1882) considers the region between Greece and Himalayas as the probable origin, while Vavilov (1926) suggested Mediterranean and Southwest Asia as primary and Ethiopia to be secondary centres of origin. He observed large-seeded cultivars mostly along the Mediterranean region and the small-seeded cultivars eastwards. Harlan (1969) considers Ethiopia to be the centre of diversity since he found maximum variability of chickpea in this region. The most probable centre of origin for chickpea could be the modern day south-eastern Turkey and northern Syria, since cultivated chickpea's progenitor (*C. reticulatum*) and other closely related wild species (*C. echinospermum* and *C. bijugum*) are found in this region (van der Maesen 1987).

There are two distinct types of chickpea, 'Kabuli' and 'Desi'. These two groups differ in their geographic distribution and also have different plant architecture. The kabuli types are mostly

found in the western Mediterranean region and the desi types are found along eastern Mediterranean to central Asia and in the Indian subcontinent. Kabuli types (also known as *macrosperma)* are generally taller, have large cream or beige colored and 'ram's head' seeds and white flowers. Desi types (also known as *microsperma*) are generally smaller in stature with small leaflets, pods and seeds. They possess predominantly pink colored flowers. The desi types exhibit wider range of variability compared to kabuli's with regards to color of seed, pod, flower and vegetative parts, seed shape and surface. Kabuli chickpea seems to have evolved from the desi types (Moreno and Cubero 1978).

3. CROP SYSTEMATIC

The genus *Cicer* is a member of the family Leguminosae and the sub-family Papilionoideae. It was previously placed in the Vicieae tribe but based on Kupicha's (1977) detailed taxonomical evidence it is now classified under a separate monogeneric tribe Cicereae Alef. Most of the *Cicer* species are diploids with 2n=2x=16 chromosomes. Based on cytological studies the chickpea karyotype has the following features: single pair of long, satellited and sub-metacentric chromosome; six pairs of medium-sized chromosome that have metacentric to sub-metacentric centromere; and a pair of short, metacentric chromosome (reviewed by Gupta and Bahl 1983). The different species of *Cicer* have two distinct karyotypes – symmetrical and asymmetrical. The karyotypes of *C. arietinum, C. echinospermum, C. reticulatum, C. anatolicum* and *C. songaricum* are of asymmetrical type and all the remaining species are of symmetrical type.

Depending upon the different morphological traits, geographical distribution and life span four sections (monocicer, chamaecicer, polycicer and acanthocicer) have been recognized in the genus *Cicer* (reviewed by van der Maesen 1987). Different species included under the four sections are: (i) *Monocicer* - *C. arietinum* (cultivated species) along with seven annual wild species (*C. reticulatum, C. echinospermum, C. pinnatifidum, C. judaicum, C. bijugum, C. yamashitae, C. cuneatum*) (ii) *Chamaecicer* - includes *C. chorassanicum* M. Pop. [a annual] and *C. incisum* (Willd) K. Maly [a perennial] (iii) *Polycicer* - 23 perennial species are included under this in the section and (iv) *Acanthocicer* - seven woody perennial species.

4. SPECIES RELATIONSHIP

The genus *Cicer* includes 9 annual and 35 perennial species (van der Maesen 1987). Only one species, *C. arietinum*, is cultivated. Inter-specific relationships among the *Cicer* species have been reported based upon crossability data (Ladizinsky and Adler, 1976; Pundir and Van der Maesen, 1983), seed storage protein analyses (Ahmed and Slinkard, 1992) and allozyme markers (Kazan and Muehlbauer, 1991; Ahmad *et al.,* 1992). Based on crossability, the *Cicer* species have been classified into three groups: Group 1 - *C. arietinum, C. reticulatum* and *C. echinospermum*; Group 2 - *C. judaicum, C. pinnatifidum* and *C. bijugum*; and Group 3 - *C. cuneatum*. The *Cicer* species are classified into four different phylogenetic groups based on allozyme pattern, storage proteins and molecular marker data: Group 1 - *C. arietinum, C. reticulatum* and *C. echinospermum*; Group 2 - *C. judaicum, C. pinnatifidum* and *C. bijugum*; Group 3 - *C. chorassanicum* and *C. yamashitae* and Group 4 - *C. cuneatum*. *C. reticulatum* and *C. echinospermum* are more closely related to the cultivated species, *C. arietinum* than the other species in group 2 and 3. Further, species in group 2 (compared to group 3) are more closely related to those in group 1. *C. cuneatum* forming an independent group exhibited the largest distance from *C. arietinum*. Three perennial species (*C. anatolicum, C. sonagaricum* and *C. microphyllum*) are included in the third phylogentic group along with *C. chorassanicum* and *C. yamashitae* (Tayyar and Waines 1996; Gargav *et al.,* 2001).

Molecular markers have also been used in chickpea diversity studies. AFLP-based genetic diversity studies of annual and perennial species identified two different clusters; the first cluster included *C. montbretii, C. isauricum and C. anatolicum* (Sudupak *et al.,* 2004). The second cluster was divided into two subclusters: (i) subcluster 1 – included one perennial, *C. incisum* and three annuals (*C. pinnatifidum, C. judaicum* and *C. bijugum*) (ii) subcluster 2 – had three annuals (*C. echinospermum, C. reticulatum* and *C. arietinum*).

5. PLANT MORPHOLOGY AND FLORAL BIOLOGY

Plant morphology

Chickpea is herbaceous annual with a robust and long tap root system. The strong tap root system of chickpea enables it to withstand dry conditions. The root parenchymatous tissue of *C. arietinum* is rich in starch. Rhizobium bacteria, capable of fixing atmospheric nitrogen are present in the symbiotic nodules developed on the roots.

Scale-like structures are present on the first few nodes of the main stem followed by formation of alternate compound (pinnate) leaves. Usually the fully formed leaves developed after the sixth node. Rachis is 25 to 30 cm long, ending in a terminal leaflet. The leaflets (average 11 to 19) are sub-sessile with opposite or alternate arrangement. They are ovate-oblong to elliptic with serrated margins. The base of leaflets is cuneate or rounded with either rounded or acuminate top. Mutations for leaf size (like simple/small or tiny leaves; narrow leaflets, broad leaflets or fewer leaflets) and rare forms with altered, spiral phyllotaxy have been reported. Stipules may be ovate or triangular. Glandular and non-glandular trichomes densely cover the entire surface of the plant, except the corolla. Three types of trichomes are present in chickpea: short stalks, multicellular stalks (both glandular) and uni-cellular, non-glandular hairs. A highly acidic fluid containing malic, oxalic and citric acids is produced by the glandular trichomes. These acids play a role in defense against pests such as aphids, Lucerne flea and red-legged earth mite. Soil bound phosphate and nutrients are solubilized by the acids secreted through the roots.

Stems are hairy, may be straight or flexuous with pronounced ribs, produced by thickened collenchyma cells. Depending upon the environmental conditions the height of the plant varies from 20 to 100 cm and under favorable growing conditions it could reach up to 150 cm. Three kinds of branches are produced in chickpea: primary, secondary and tertiary. Primary branches can either grow from the seed shoot or from buds at the lowest nodes. The number of primary branches can vary from 1 to 8 depending upon the growing conditions, cultivar and cultural practices. These are thick, strong and woody, and determine the plant habit. Secondary branches are less vigorous than the primary branches and are produced from the buds on the primary branches. The number of secondary branches determines the number of leaves and thereby the net photosynthetic area, influencing the total yield of the crop. Buds present on secondary branches give rise to leafy tertiary branches which carry fewer pods. Tertiary branches are not always present. Based on the angle of branching (from the vertical stem) five growth habits are observed in chickpea: erect, semi-erect, spreading, semi-spreading and prostrate. The erect or semi-erect varieties are suitable for mechanical harvesting.

The pod is typically inflated ending in a mucro that resembles a thorn. Pod size is not influenced by the environmental changes but varies greatly between cultivars. The length of pod ranges from 15 to 30 mm. It is not an easy task to describe pod shape in chickpea. However, based on different regions (dorsal and ventral) and zones (apical and basal) the pod shapes fall in the category of rhomboid, oblong and ovate. But, these shapes represent only few but not all of the shapes found in chickpea. The thickness and width of the pod ranges between 7 to 14 mm and 8 to 15 mm respectively. Chickpea pods have three layers: exocarp, mesocarp and endocarp.

The exocarp possesses stomata and hairs, mostly glandular. The number of pods per plant is highly influenced by the year, location, sowing dates and other factors. The number of pods usually ranges from 20 to 150. The number of seeds per plant varies from one to three.

Chickpea seeds are distinctly beaked and often ram's head shaped and strongly wrinkled or ribbed. Sometimes quasi-spherical and intermediate forms are also observed. The coat can be smooth or tuberculate. The post-chalazal bundles vary in degree of forking and in depth. The cotyledons are separated by a groove, intended in the wrinkled seeds but this is not observed in spherical and nearly spherical seeds. The beak is produced by the radicle tip and its colour is sometimes different from that of seed coat. The hilum is small, indented, elliptical or sub-orbicular, whitish or grayish with a colour rim or corona (halo). The seed surface is not completely smooth and the degree of roughness seems to be a varietal trait. Seed roughness and shape are highly correlated and also depends on cotyledons, but colour is mainly in the testa, pure maternal tissue. Colour of testa and cotyledon are generally different. Seed (coat and cotyledon) colour varies from whitish and creamy to deep black. Different shades of yellow orange, red, green and brown (most often) are also observed. Sometimes small black dots are observed on the seed *i.e.* dotted seeds. Length and width of seed can vary between 4-12 and 4-8 mm, respectively. The weight of the seed generally falls in the range of 0.1 to 0.75 g and is a very stable characteristic, almost as stable as the size of the pod.

Stages of development

The seeds germinate in about 7-15 days after sowing depending upon moisture levels, temperature and sowing depth. Chickpea has hypogeal germination, *i.e.* the cotyledons remain underground inside the seed coat nourishing the rapidly growing roots and shoots. Erect shoot is produced from the plumule and the first leaves produced are scales. Two to three pairs of leaflets along with a terminal leaf are the first true leaves. Hypocotyl is absent in chickpea. Root growth is faster at pre-flowering stage but continues under favorable conditions until maturity. The primary root is long and develops branches very early. Roots have no exodermis but possess a hairy epidermis and thin walled endodermis. In well-structured soils, roots can penetrate more than three meters deep.

Chickpea's growth habit is indeterminate, *i.e.* continued vegetative growth even after initiation of flowering. Hence, there is often a sequence of leaf, flower bud, flower and pod development along each branch. The duration of vegetative growth prior to flowering ranges between 40 to 80 days depending on the variety, location, environmental and soil conditions. During the transition from leaf buds to flower buds on the stem several pseudo–flowers or false flower buds develop. Excessive vegetative growth resulting due to favorable soil moisture and temperature especially during early reproductive growth stages is a problem of long growing season environments, as in some parts of India. The time taken from fertilization to the first appearance of a pod is about six days under favorable conditions and during the next three to four weeks the seed fills up. Subsequent to pod setting there is rapid growth of pod wall (first 10 to 15 days) and the seed growth mainly occurs later. Early (first 20-30 days) damage to the pod results in seed abortion. Seed filling and subsequent seed size is highly dependent on weather conditions. Leaf senescence follows the full development of pods and completion of seed filling. Availability of soil moisture extends flowering and podding on the upper nodes; flowering ceases upon soil moisture depletion.

Floral biology

Chickpeas have solitary papilionaceous flowers in axillary racemes. Sometimes two or rarely three flowers racemes are also found. Small (~1.5 mm long) and triangular bracts are found in

chickpea. Bracts are triangular and small. The racemal peduncle is about 6-30 mm long; usually it is 13-17 mm and ends in arista. The pedicels (6 to 13 mm) are straight when flowering and curved when bearing fruit. Chickpea has a glabrous calyx (6 to 13 mm) and has five partly joined sepals. Peduncle and calyx are hairy. The corolla is veined and may be pink, purple, red, white, blue, greenish white or pinkish white in colour. The standard petal or vexillum (8 -11 mm long) is wide, clawed, glabrous or scarcely pubescent and does not have any glandular hairs. The wings are free, obovate and about 6-9 mm long. The keel is incurved with 2-3 mm long pedicel. The stamens are diadelfous, 9 fused stamens and the 10^{th} stamen is free (9+1). Usually the filaments are 6 to 8 mm long and the anthers are dorsifixed. The pollen is orange colored and it has a coarse granular membrane. Ovary is ovate and covered by predominantly glandular hairs on its surface. It is 2 to 3 mm long and 1 to 1.5 mm wide with 2, sometimes 4, ovules. The style is linear, upturned and 3 to 4 mm long with a globose stigma.

6. INHERITANCE OF ECONOMICALLY IMPORTANT GENES / CHARACTERS

Reports are available on inheritance of several economically important traits in chickpea (Table 1). However, allelic relationships of genes were established only for few traits. Thus, there are chances that different gene symbols were proposed by different studies for the same gene. Inheritance of some important traits are described below:

Growth habit

The growth habit of chickpea varies from prostrate to erect, and plants have primary, secondary and tertiary branches. The inheritance of branching habit (basal vs umbrella type) and growth habit (erect vs prostrate) was reported to be monogenic (Table 1). Mutants, one spontaneous (E100YM) and one induced (JGM 1), with short internodes and compact growth habit (called brachytic mutant) were reported. Genetic studies indicated that the brachytic trait is monogenically controlled and these mutants have different genes for this trait (Dahiya *et al.*, 1990, Gaur *et al.*, 2008a). A mutant (BGD 9971) with determinate growth habit was identified and the determinate growth habit was found to be under control of two recessive genes (Hegde 2011).

Knights (1993) reported a spontaneous stem fasciation mutant and found a single recessive gene '*fas*' for this trait. An induced stem fasciation mutant was also reported and this trait was also controlled by a single gene (Gaur and Gour 1999). The studies on allelic relationships of genes indicated that the stem fasciation genes in the spontaneous and induced mutants are non-allelic (Srinivasan *et al.*, 2006).

Time of flowering

Time of flowering has been found to be a simply inherited trait. A major gene (*ppd*) for flowering time was identified from the desi chickpea landrace ICC 5810 (Or *et al.*, 1999). Similarly, a major gene (*efl-1*) for flowering time was identified from kabuli chickpea cultivar ICCV 2 (Kumar and van Rheenen 2000). Hegde (2010) reported that duplicate dominant genes with cumulative but unequal effect govern flowering time in chickpea. Recent allelic studies at ICRISAT (PM Gaur, unpublished results) indicated that the gene *ppd* of ICC 5810 was not allelic to any other early flowering gene. The gene *efl-1* was also present in ICCV 96029, which has ICCV 2 as one of the parents in its pedigree. ICC 16641 and ICC 16644 had a common gene and this gene was not allelic to *efl-1* and *ppd*. Thus, three major genes for flowering time were identified.

Flower morphology and number of flowers (or pods) per axis

Two spontaneous open flower mutants (ICC 16341 and ICC 16129) are known in chickpea. Inheritance of open flower trait was studied in ICC 16129 and the open flower trait was found to be controlled by a recessive gene (Pundir and Reddy 1998). A new open flower mutant was recently identified at ICRISAT. Inheritance studies indicated that the gene for open flower trait in this mutant (*ofl-3*) is different (non-allelic) from that present in ICC 16341 (*ofl-1*) and ICC 16129 (*ofl-2*) (S. Srinivasan, unpublished results).

Chickpea has a racemose type of inflorescence and at each axis of the raceme usually one flower is borne. There are mutants that produce two or more flowers at each axis. A single recessive gene (*sfl*) was identified to control double flowered/double-podded trait (D'Cruz and Tendulkar 1970). A mutant producing 3 to 9 flowers, arranged in a cymose inflorescence, at many axis of the raceme, was identified. The number of pods set varied from 0 to 5 in each cyme. Inheritance studies indicated that a single recessive gene, designated *cym*, is responsible for cymose inflorescence and it was not allelic to *sfl* (Gaur and Gour 2002). The triple-podded trait has also been reported to be monogenic (Singh and Chaturvedi 1998). Allelic relationship studies indicated that double-flower trait (*sfld*) and triple-flower (*sflt*) traits are conditioned by different alleles recessive to single-flower trait (*Sfl*) with dominance relationship *Sfl>sfld>sflt* (Srinivasan *et al.*, 2006).

Seed characteristics

Seed coat thickness is one of the major quality aspects and plays a vital role in the final consumption. Desi and kabuli chickpea are characterized, among other things, by their seed coat being thicker in the desi than in the kabuli type. Inheritance of seed coat thickness in desi x kabuli introgression crosses found that thicker seed coat is controlled by single dominant gene or polygenes with partial dominance. Desi type segregants with thin seed coat would be a source of enhancing dal recovery percentage and also improves the possibility of consumer preference towards raw use of desi seed.

Resistance to diseases

Seven races of the pathogen showing different disease reactions have been reported from India (1 to 4), Spain (0 and 5) and California (6), of which race 0 is the less virulent strain and race 5 is the most virulent strain (Kaiser *et al.*, 1994). Inheritance of resistance to some races has been studied. The studies indicated that wilt resistance is conditioned by recessive genes. Four genes were identified for resistance to race 1, three for resistance to race 2, and two for resistance to race 4 (Table 1).

Reports available so far indicate that BGM resistance in chickpea is controlled by a few major genes. Resistance to BGM in ICC 1069 was reported to be due to a single dominant gene (*Bor*1) (Tewari *et al.*, 1985). In another study on ICC 1069, two genes with epistatic interaction were identified for BGM resistance (Rewal and Grewal 1989). Chaturvedi *et al.* (1995) found that resistance was controlled by a single dominant gene in 3 resistant parents and in two resistant parents (ICC 1069 and P 349-2) the dominant resistance genes were different (non-allelic).

TABLE 1: Economically important traits and their inheritance in chickpea

Gene symbols	Genotype and phenotype description	Reference
Early growth vigor		
Gv_1 and Gv_2	$gv_1gv_1gv_2gv_2$ = low growth vigour Any of the gene in dominant condition produces early growth vigour plant	Sabaghpour *et al.* (2003)
Growth habit and branching		
Br/br	*Br* = basal type of branching *br* = umbrella type of branching	Ayyar and Balasubramanian (1937); Argikar and D'Cruz (1963)
Hg/hg	*Hg* = érect growth *hg* = prostrate	Argikar and D'Cruz (1963)
Bu/bu	*Bu* = normal growth *bu* = bushy growth	Athwal and Brar (1964)
Bs/bs	*Bs* = normal growth habit *bs* = bushy growth habit	Singh and Dahiya (1974)
Bh/bh	*Bh* = bunchy growth *bh* = non-bunchy	Patil and Deshmukh (1975)
Pt/pt	*Pt* = normal plant type *pt* = mutant (compact) plant type	Sandhu *et al.* (1990)
Br/br	*Br* = normal plant type *br* = brachytic mutant (compact growth)	Dahiya *et al.* (1990)
Cd and *Dt*	*cdcdDt_* = determinate growth and remaining genotypes give indeterminate growth	van Rheenen *et al.* (1994)
dt1 and dt2	*dt1dt1 dt2dt2* = determinate growth	Hegde (2011)
Flower morphology		
Lvx/lvx	*Lvx* = normal vexillum *lvx* = three lobed vexillum	Rao and Pundir (1983)
Ocw/ocw	*Ocw* = inwardly curved wing petals *ocw* = outwardly curved wing petals	Gaur and Gour (2003)
ofl-1, ofl-2 and ofl-3	Any two loci in dominant state produces normal cleistogamous flower; Recessive loci will give corresponding type of open flower; double recessive give sterile deformed flowers	S. Srinivasan (unpublished)
Pods		
Rp/rp	*Rp* = normal flattened elliptical pods *rp* = round pods	Athwal and Brar (1967)
Pd_{fr}/pd_{fr}	Pd_{fr} = pendant pods pd_{fr} = horizontal pods	Patil (1967)
Number of Flowers/pods per Axis		
S/s	*S* = single-flower *s* = double-flower	Khan and Akhtar (1934)
Df/df	*Df* = single flower *df* = double flower	Athwal and Brar (1964)
Sfl/sfl	*Sfl* = single-flower *sfl* = double-flower	D'Cruz and Tendulkar (1970); More and D'Cruz (1976b); Gaur and Gour (2002)
Tpc/tpc	*Tpc* = single monocarpellary flowers *tpc* = twin polycarpellary flowers	Pundir *et al.* (1988)
Rtf	*rtf* = triple-flower	Singh and Chaturvedi (1998)

Gene symbols	Genotype and phenotype description	Reference
Cym	*cym* = cymose inflorescence (multi-flower trait)	Gaur and Gour (2002)
Sfl/sfl^{d} or *sfl*^{t}	Single-flower = *Sfl _ Cym _*	Srinivasan *et al.* (2006)
Cym/cym	Double-flower = *sfld sfld Cym_ or sfld sflt Cym _*	
	Triple-flower = *sflt sflt Cym_*	
	Multi-flower = *Sfl _ cym cym*	
	Double-multiflower = *sfld sfld cym cym or sfld sflt cym cym*	
	Triple-multiflower = *sflt sflt cym cym*	
Time of Flowering		
Ppd/ppd	*Ppd* = photoperiod sensitive	Or *et al.* (1999)
	ppd = photoperiod insensitive	
Efl-1/efl-1	*Efl-1* = late flowering	Kumar and van Rheenen (2000)
	efl-1 = early flowering	
Efl-3/efl-3	*Efl-3* = late flowering	Hegde (2010)
(*ppd=efl-2*)	*efl-3* = early flowering	
Efl-4/efl-4	*Efl-4* = late flowering	PM Gaur (unpublished)
	efl-4 = early flowering	
Seed characteristics (Seed coat colour, cotyledon colour, seed size, seed shape and seed surface)		
R/r	*R* = rough seed coat	Balasubramanian (1937)
	r = smooth seed coat	
T^1/t^1	T^1 = darkening of seed color	Balasubramanian (1937);
	t^1 = no darkening of seed color	Balasubramanian (1950);
		Balasubramanian (1951)
T^2/t^2	T^2 = darkening of seed color	
	t^2 = no darkening of seed color	
T^3/t^3	T^3 = dark brown testa in combination with *P*	Balasubramanian (1951)
	t^3 = yellow brown testa	
T^4/t^4	T^4 = black testa with or without *P*	Balasubramanian (1951)
	t^4 = yellowish brown testa	
P^r/f^r	P^r = no color effect in the presence of *B*, dilute the pigment in the absence of *B* and make the seed coat darker when *B* and *P* both are present	Balasubramanian (1951)
	f^r = no effect on testa color	
Gr/gr	*Gr* = yellow cotyledons	Argikar and D'Cruz (1962)
	gr = green cotyledons	
Gr/gr	*Gr* = brown testa	Argikar and D'Cruz (1962)
	gr = green testa	
S_1/s_1	S_1 = reddish brown testa	Brar and Athwal (1970)
	s_1 = fawn testa	
S2/s2, S3/s3	*S2, S3* = no effect on testa colour	
	s2 = seal-brown testa (epistatic over *S1*)	
	s3 = green testa (epistatic over the alleles at *S1* and *S2* loci)	
S4/s4	*S4* = produces dark grey testa in the presence of *S2* and black testa with *s2*	
	s4 = fawn testa	
Brsc/brsc	*Brsc* = brown testa	D'Cruz and Tendulakar (1970);
	brsc = white/yellow testa	Patil and Deshmukh (1975)
Wrsa and *Wrsb*	Wrinkled seed dominant over round seed	D'Cruz and Tendulakar (1970)
Brt/brt	*Brt* = brown seed coat	Pimplikar (1943); More and

Gene symbols	Genotype and phenotype description	Reference
	brt = orange/yellow seed coat	D'Cruz (1970, 1976b)
Rs/rs	*Rs* = rough seed surface *rs* = smooth seed surface	More and D'Cruz (1970)
Rsa Rsb/ rsa rsb	*Rsa Rsb* = rough seed surface *rsa* = smooth seed surface *rsb* = smooth seed surface	More and D'Cruz (1976a)
Wrsa, Wrsb and *I-Wrsa-Wrsb*	Wrinkled seed dominant to round seed	Patil and Deshmukh (1975)
$Blsc_a$ $Blsc_b$/ $blsc_a$ $blsc_b$	$Blsc_a$ $Blsc_b$ = black seed coat $Blsc_a$ = yellow seed coat $Blsc_b$ = brown seed coat	Reddy and Chopde (1977a)
Ycot/ycot	*Ycot* = yellow cotyledons *ycot* = green cotyledons	Nayeem *et al.* (1978)
Rss_a and Rss_b	$Rss_a\_Rss_b\_$ = rough seed surface All other combinations seed surface is smooth	Reddy and Nayeem (1978)
Brsd/brsd	*Brsd* = brown seed coat *brsd* = white seed coat	Reddy and Nayeem (1978)
Wss_a and Wss_b	$Wss_a\_Wss_b\_$ = wrinkled seed All other combinations seed shape is round	Reddy and Nayeem (1978)
Gsc	Produces green seed coat colour in presence of *Bco* and *Pco*	Ghatge *et al.* (1985)
Ycot	Produces yellow seed coat in presence of *Bco* and *Pco*	
Gsc and *Ycot*	Together produces brown seed coat in presence of *Bco* and *Pco*	
$Blsc_a$ and $Blsc_b$	Together produces black seed coat in presence of *Bco* and *Pco*	
Shp/shp	*Shp* = angular seed shape *shp* = round seed shape	Kazen *et al.* (1993)
A, B and *C*	*A_B_C_* = Brown seed coat *aabbcc* = White seed coat *A_B_cc* = green *A_bbC_* = orange *A_bbcc* = yellow	Meena *et al.* (2004)
Sd_1 and Sd_2	$Sd_1\_sd_2sd_2$ = normal seed size $sd_1sd_1Sd_2\_$ = small seed size $sd_1sd_1sd_2sd_2$ = medium seed size	Upadhyaya *et al.* (2006)
Root nodulation		
Rn1/rn1, Rn2/rn2 and *Rn3/rn3*	*Rn1, Rn2* and *Rn3* = nodulating phenotype *rn1, rn2* and *rn3* = nonnodulating phenotype	Davis *et al.* (1986)
Rn4/rn4 and *Rn5/rn5*	*Rn4* = nodulating phenotype *rn4* = nonnodulating phenotype *Rn5* = nodulating phenotype *rn5* = nonnodulating phenotype	Davis *et al.* (1988)
Rn6/rn6	*Rn6* = nodulating phenotype *rn6* = nonnodulating phenotype	Singh *et al.* (1992)
Rn8/rn8	*Rn8* = nodulating phenotype *Rn8* = nonnodulating phenotype	Singh and Rupela (1998)
Fusarium wilt		
H_1/h_1 (race 1)	H_1 = wilt susceptible h_1 = wilt resistant	Kumar and Haware (1982); Singh *et al.* (1987); Mayer *et al.*

Gene symbols	Genotype and phenotype description	Reference
		(1997)
Rfo/rfo	*Rfo* = susceptible to wilt *rfo* = resistant to wilt	Sindhu *et al.* (1983)
H_1, H_2 and H_3 (race 1)	$h_1h_1h_2h_2h_3h_3$ = wilt resistant $h_1h_1H_2H_2h_3h_3$, $H_1H_1h_2h_2h_3h_3$ and $H_1H_1H_2H_2H_3H_3$ = late wilting $H_1H_1H_2H_2h_3h_3$ = early wilting	Smithson *et al.* (1983)
H1 and *H2 (race 1)*	*H1_H2_* = early wilting *H1_h2h2* and *h1h1H2_* = late wilting *h1h1h2h2* = resistant	Upadhyaya *et al.* (1983)
A and *B* (race 2)	*A_B_* = late wilting *A_bb* and *aabb* = early wilting *aaB_* = complete resistance	Gumber *et al.* (1995)
A, B and *C* (race 2)	*A_bb_ _*, *aaB_ _ _* and *A_B_C_* = wilt tolerant *aabb_ _* = wilt resistant *A_B_cc* = wilt susceptible	Kumar (1998)
Foc-0 (race 0), *foc-4* (race 4) and *foc-5* (race 5)	Resistance in each race is controlled by a single recessive gene	Tekeoglu *et al.* (2000)
H1, H2, H3 and *H4*	Depending upon presence of number of segregating loci in recessive condition produce resistance	Girase and Deshmukh (2002)
Ascochyta blight		
Rar1/rar1	*Rar1* = susceptible to Ascochyta blight *rar1* = resistant to Ascochyta blight	Singh and Reddy (1983)
Rar2/rar2	*Rar2* = resistant to Ascochyta blight *rar2* = susceptible to Ascochyta blight	Singh and Reddy (1983)
Arr_1, Arr_2 and arr_3	Arr_1, Arr_2 and arr_3 = resistant to ascochyta blight arr_1, arr_2 and Arr_3 = susceptible to ascochyta blight	Tewari and Pandey (1985)
	Arc1 and *Arc2* *Arc3* and *Arc4* *Arc5 (Arc3 or Arc4)* and *arc 1*	Dey and Singh (1993)
R_1 and R_2	Both genes in dominant condition control resistance	Mahendra Pal *et al.* (1999)
R_3 and R_4	Both genes in dominant condition control resistance	
Ar1/ar1 (pathotype I)	*Ar1* = susceptible *ar1* = resistant	Udupa and Baum (2003)
Ar2a and *Ar2b*	Both genes in recessive condition (*ar2a ar2b*) conferring resistance	
*A_B_C_*	Disease reaction is variable depending on the number of dominant and recessive genes	Bharadwaj *et al.* (2010)
Botrytis Gray Mold		
Bor_1	Bor_1 = botrytis cinerea resistant 1 bor_1 = botrytis cinerea susceptible 1	Tewari *et al.* (1985)

7. BREEDING OBJECTIVES

High yield potential

Despite release of large number of cultivars, the average yield of chickpea in India and also in the world continues to remain less than one ton per hectare. This is largely because of wide gap between realized and potential yields. Though bridging the yield gaps has the greatest potential of enhancing the average yield, there is also a need of enhancing yield potential of chickpea.

Thus, enhancement of yield potential is always an important objective in chickpea breeding programs. Restructuring of plant type has played a key role in enhancing yield potential of several crops, including wheat and rice. There is a need for bringing a drastic change in the plant type of chickpea for bringing a breakthrough in chickpea productivity.

Reduction in crop duration

Length of the growing period (days to maturity) is the most important trait for crop adaptation in different environments. Days to maturity in chickpea ranges from 80 to 180 days depending on genotype, soil moisture, time of sowing, latitude and altitude. However, in at least two-thirds of the chickpea growing area, the available crop-growing season is short (90-120 days) due to risk of terminal drought or heat stress at the critical stage of pod development and seed filling (Gaur *et al.*, 2008c). Short duration cultivars escape terminal stresses and enhance opportunities for inclusion of chickpea in cropping systems where a narrow window is available for chickpea. Therefore, development of early-maturing varieties is a major objective in chickpea-breeding programs.

Responsive to high input conditions

Since times immemorial chickpea has been grown on marginal soils under rainfed conditions with minimum inputs. The available cultivars, which have been developed keeping in mind these growing conditions, do not respond favorably to high input (application of fertilizer and irrigations) conditions. High input conditions, particularly in deep black soils (vertisols), may stimulate excessive vegetative growth leading to poor pod set, lodging, reduced harvest index, reduced grain yield and quality. This was one of the reasons for reduction of chickpea area in northern India. There is a need to have a separate breeding program to develop cultivars responsive to high input conditions for improving the competitiveness of chickpea with other crops in high input conditions. Restructuring of plant type, which was a key to enhancing productivity of wheat and rice, may be needed for developing chickpea cultivars responsive to high input conditions.

Tolerance to abiotic stresses

Terminal drought

Drought is the most important constraint to yield in chickpea accounting for about 50% yield reduction globally (Ryan 1977). It generally occurs at the terminal stage as the crop is generally raised on conserved soil moisture under rainfed conditions. It reduces plant growth, causes early senescence and reduces pod and seed development. Drought is not only a problem of tropics and the semi-arid tropics but also a problem in the temperate environment where crop duration is expanded because of the susceptibility of the crop to chilling, thereby predisposing the crop to terminal drought.

Reproductive stage heat stress

In addition to terminal drought, heat stress has become a major constraint to chickpea production in India because of a large shift in chickpea area from the cooler, long season environments (northern India) to warm, short-season environments (southern India); increase in area under late sown conditions due to escalating cropping intensity and emergence of new cropping systems; and reduction in winter period and large fluctuations in temperatures due to

climate change. The overall temperatures are further expected to rise due to climate change. Reproductive growth stage (flowering and podding) in chickpea is known to be very sensitive to changes in external environment, and heat stress at this stage leads to reduction in seed yield. Drastic reductions in chickpea seed yields were observed when plants at flowering and pod development stages were exposed to high (35°C) temperatures (Summerfield *et al.,* 1984). Heat stress adversely affects pollen viability, fertilization and seed development, therefore, reducing harvest index and grain yield. Chickpea cultivars with enhanced heat tolerance are needed to minimize yield losses in all chickpea growing conditions where the crop is exposed to high temperatures at the reproductive stage. Heat tolerant cultivars will be more resilient to sowing dates and enhance opportunities for expanding chickpea area in new niches and cropping systems, such as rice-fallows.

Soil salinity

Legumes, in general, are sensitive to salinity, and within legumes, chickpea, faba bean and pea are more sensitive than other food legumes. Saline soils are very common in north and north-west India. The soil salinity adversely affects germination resulting into poor plant stand. The chickpea plants show reduction in growth, high anthocynin pigmentation on the foliage in *desi* type and yellowing of foliage in *kabuli* type, reduction in biomass, seed size and grain yield. Only salt tolerant cultivars can be grown successfully in soils having ECe higher than 4.0 dS/m.

Chilling temperatures

Most chickpea cultivars are susceptible to chilling temperature at flowering. These cultivars continue to set flowers but fail to set pods when mean of maximum and minimum temperatures fall below 15°C. Chilling temperature adversely affects size and viability of pollen and ovules, anther dehiscence, pollen germination and tube growth, and fertilization. The implications of low temperature stress on chickpea have been reviewed by Croser *et al.* (2003b).

Resistance to biotic stresses

Fusarium wilt

It is the most important root disease of chickpea caused by *Fusarium oxysporum* f. sp. *ciceri.* It has been reported from almost all the chickpea growing regions of the world. It is especially important in dry and warm chickpea growing areas. It is a typical vascular disease that causes browning and blackening of xylem and affected seedlings first show drooping of the leaves and then collapse. Early wilting is highly devastating and causes 77-94% yield losses, while late wilting causes 24-65% yield losses.

Dry root rots

It is caused by *Rhizoctonia bataticola.* It is a serious disease under high temperature (>30°C) and dry soil conditions. The whole plants dry up and turn straw–colored. Roots become brittle and have only a few lateral roots or none at all. There has not been much work on identification of races for dry root rot resistance. Although no absolute resistance has been identified in the cultigens there are indications for the existence of some useful resistance in the germplasm lines.

Ascochyta blight

It is caused by *Ascochyta rabiei* (Pass.) Labr. It is a highly devastating foliar disease of chickpea, prevalent in northwestern India. It occurs mainly in areas where cool, cloudy and humid weather (15-25°C temperature and >150 mm rainfall) occurs during the crop season. Thus, yield losses largely depend on weather conditions during the crop season. The typical symptoms of AB are brown lesions, which eventually lead to collapse of the tissues. The lesions on stem sometimes girdle and the stem may break off. In severe case the disease kills the whole plant.

Botrytis gray mold

It is caused by *Botrytis cinerea* Pres. It is an important foliar disease of chickpea prevalent in north-west and north-east plains of India covering mainly *Tarai* region which is characterized by high humidity and high temperature. The fungus *B. cinerea* is a necrotrophic fungus well known for its extensive host range, extreme variability and wide adaptability. Though it infects all aerial parts of the plant, flowers are the most severely affected leading to poor or no pod set resulting in low yields.

Stunt

Chickpea stunt has been reported to cause significant yield losses occasionally in some pockets. Discoloring (yellow, orange or brown) of foliage, browning of phloem and stunting of growth are the main features of this disease. Many viruses have been identified that can cause this disease. Chickpea chlorotic dwarf monogeminivirus (CCDV) and chickpea luteovirus (CpLV) were important in India and Pakistan. Few sources of resistance have been found which could be used as parents in the breeding programs.

Root nematodes

The major nematodes known to affect chickpea are root knot nematodes (*Meloidogyne* spp.), cyst forming nematodes (*Heterodea* spp.) and lesion nematodes (*Prathylenchus* spp.). Root knot nematodes are of economic importance in Indian subcontinent. Many germplasm lines with low to moderate level of resistance to root knot nematodes have been identified, but not much progress has been made in development of resistant varieties.

Pod borer

Pod borer (*Helicoverpa armigera* Hubner) is the most important pest of chickpea worldwide. It is highly polyphagous pest and can feed on various plant parts such as leaves, tender shoots, flower buds, and immature seeds. The extent of global losses to chickpea by this pest is estimated at over US$ 500 million (Ryan 1997).

Market-preferred seed traits

The most important and market price determining quality traits in chickpea are appearance (shape and color) and size of the grain. The desi seed is usually consumed as split (dhal) and flour (besan); and kabuli types are generally used in whole grain form. Therefore, the preferred seed traits differ for the two types based on their different forms of consumption. Medium sized seed (16 to 22 g 100-seed^{-1}) usually with golden yellow seed coat color desi types are mostly preferred. However, there are small niche markets for the green and black-seeded chickpeas.

Large seeded desi types fetch a modest premium rates. High milling efficiency is an important trait for desi chickpeas as 70% of desi chickpeas are split and made into dal and some portion is further processed into besan. Seed size is the most important quality trait for kabuli chickpeas. Since kabuli chickpea is usually cooked as whole grain, seed volume expansion and cooking time are other important traits. In general, large (>30 gm 100-seed^{-1} or 8-9 mm in diameter) seed size attracts higher price premium. There is increasing demand for extra-large (>50 gm 100-seed^{-1}) kabuli cultivars and these command very high premiums. White or beige seed coat color and 'ram's head' seed shape are very much preferred by the market.

Nutritional quality

There is no price premium for the nutritionally improved chickpea cultivars in the present day market. But, chickpea seeds are a good source of high quality protein, carbohydrates, dietary fibre, minerals (Fe, Zn, Ca and Mg) and other important nutrients (β-carotene, unsaturated fatty acids etc.) that are essential for human health and development. Protein content of present day cultivars is usually about 18–22% whereas much larger variability (12.4–32.5%) exists in the cultivated and wild species which could potentially be exploited to develop high protein lines (≥25%). Transgenic chickpea produced by introducing sunflower seed albumin gene resulted in an increase of 24-94% of methionine (a limiting amino acid in chickpea) compared to the non-transgenic chickpea (Higgins *et al.*, 2004). In developed countries, there is already a growing interest in use of chickpea as functional food. There has been minimal effort in the improvement of nutritional quality of chickpea even though there are reports of genetic variability for different quality traits. There is a need to screen for genetic variability in important minerals like zinc and iron coupled with medicinally important nutrients like dietary fibre, β-carotene and linoleic acid, a polyunsaturated fatty acid and the variation could be exploited in breeding programs.

8. BREEDING METHODS

Chickpea is a self-pollinated crop and thus the breeding methods applicable for autogamous crops are employed. The commonly used methods are described here.

Introduction

Germplasm introduction, evaluation and selections from the introduced germplasm have been successfully used in development of cultivars in many crops, including chickpea. Nature of the introduced material, soil and climatic conditions decides the success rate of any plant introduction. Introduction is cheap and a fast way of developing varieties therefore, it is suitable for countries with limited resources. Chickpeas introduced into a new area may be directly released as varieties after their evaluation for yield and other important traits. G109-1, a bruchid resistant line was selected from a Turkish variety introduced into India.

Pure line Selection

The genetic variability present within the landraces provides an opportunity of further selections and development of pure lines. The pure lines are evaluated for yield and resistance/tolerance to key stresses and other agronomic traits. The lines which are found better than the standard check(s) in one or more traits can be released as cultivars. The notable varieties developed by this method include Annegeri, Chaffa, Jyoti, Pragati, Ujjain 21, Ujjain 24, Warangal, CO 2, CSJ 8962, DCP 92-3, JG 62, JG 315, KGD 1168 and KRIPA.

Hybridization

Hybridization is used to combine traits from two or more parental lines and create genetic variability. Hybridization followed by backcross breeding is used to incorporate one or few traits from a germplasm line, sometimes a wild species, to a well-adopted variety. Selection of good parents is the first important step in hybridization. The selection of parents depends upon the objective of the breeding program, if it is to replace the existing variety than an adapted variety should be used as one of the parents along with a parent that complements the adapted variety as the second parent. Diverse parents are to be used if the objective is to widen the genetic base. Crossing in chickpea is a very tedious job owing to its small and delicate flowers. Emasculation may damage the floral parts resulting in low rate of success which is usually between 10-50%. The success rate of hybridization also depends upon genotype, temperature and humidity. Single, three-way or multiple crosses are used depending upon the objective of the breeding program.

Pedigree, bulk or different modifications of these methods are used in handling segregating generations in chickpea. The pedigree method is not in much practice in its original form as it is cumbersome and thus can be employed to limited number of crosses. A combination of bulk and pedigree methods is very commonly used. There are mixed reports on gains from early generation testing and selections for yield in chickpea. Selections for qualitative and simply inherited traits can be effectively made in early segregating generations (F_2 and F_3), but for yield and other complex traits the selections should start at later generations. Thus, most chickpea breeding programs start selection of plants from F_4 or later generations. Most of the recent chickpea varieties in India have been developed through hybridization. These include Avrodhi, Gaurav, Radhey, Vijay, Vishal, BG 261, BG 256, ICCV 10, KPG 59, Phule G 5, K 850, PBG 1, Pusa 372, GCP 101, GNG 469, GNG 663, Pusa 391, GPF 2, BG 1003, CO3, JG 11, JG 130 and BGD 72.

Single seed descent (SSD) and rapid generation advancement (Gaur *et al.*, 2007) methods can be used for reducing the time required to reach the desired level of homozygosity. Development of double-haploids is another desired approach for saving time in reaching homozygosity. There is a recent report on success in regenerating double-haploids through anther culture in chickpea (Grewal *et al.*, 2009). This has opened opportunities for exploiting haploid technology in chickpea breeding programs.

There is a need to enhance precision and efficiency of selections in the segregating generations for higher and rapid genetic gains. Precision in selection for resistance/tolerance to stresses can be improved by screening under controlled environmental conditions or at hot spot locations. Most of the chickpea breeding programs in India have developed wilt-sick fields for *fusarium* wilt resistance screening. Screening for resistance to ascochyta blight and botrytis gray mould is generally carried out at hot spots in northern India.

Marker-assisted selection (MAS) can greatly improve precision and efficiency of selections and thus integration of MAS in the breeding programs is very much needed. Molecular markers facilitate indirect selection for traits that are difficult or inconvenient to score directly (*e.g.* root traits, resistance to root knot nematodes), pyramiding of genes from different sources (*e.g.* bringing together ascochyta blight resistance genes from different donors) and combining resistance to multiple stresses (*e.g.* resistance to *fusarium* wilt and ascochyta blight). Excellent progress has been made in developing linkage map of chickpea and identifying molecular markers for the quantitative trait loci (QTL)/genes controlling root traits and resistance to *fusarium* wilt and ascochyta blight in chickpea (reviewed by Millan *et al.*, 2006, Gaur *et al.*, 2008b; Kumar *et al.*, 2011).

Mutation Breeding

Mutation breeding is very useful in creating novel genetic variability. Though spontaneous mutations occur continuously in nature, the frequency of such mutations is very low and most mutants are eliminated from the population because of their selective disadvantages. Frequency of mutations is enhanced through mutagenesis using physical or chemical mutagens. Mutation breeding is generally used to improve a well-adapted variety for a deficient trait or creating a novel trait (*e.g.* determinate growth habit, open flower trait). Mostly gamma rays and fast neutrons have been used in chickpea for developing mutant varieties. Chickpea seed is most often used for mutagen treatment and in some cases pollen grains were also used. Several chickpea varieties have been developed through mutation breeding in India. These include Pusa 408 (Ajay), Pusa 413 (Atul), Pusa 417 (Girnar), RS 11, RSG 2 (Kiran) and WCG 2 (Surya).

Transgenic technology

Recent advances in cloning and plant transformation protocols allows for the transfer of genes across organisms. Transgenic technology makes it possible to improve traits which have no or limited genetic variability in the cultivated and cross-compatible wild species (primary and secondary gene pools). Efficient regeneration protocols are now available for chickpea which have made it possible to introduce any desired gene from any source in to chickpea.

9. IMPORTANT ACHIEVEMENTS

High yield potential

The superiority in yield over the local check is the first requirement for release of a cultivar. The recently released varieties have high yield potential than the earlier released cultivars. The front line demonstrations indicate that the new cultivars give about 25% higher yield than the local cultivars. High yielding lines have also been developed through interspecific hybridization. High-yielding kabuli lines were developed by crossing cultivated species with *C. reticulatum* and *C. echinospermum* (Singh and Ocampo 1997). There was a yield advantage of 39% over the cultivated parent in nine F_7 lines and additionally these lines did not have any known undesirable traits from the wild species. PUSA 1103, a high-yielding desi chickpea variety released for cultivation was developed using *C. reticulatum* as one of the parents (Yadav *et al.*, 2002 a,b).

Reduction in crop duration

Excellent progress has been done in development of early maturing cultivars in chickpea (Gaur *et al.*, 2008c). The first landmark variety was ICCV 2 which is perhaps the world's earliest maturing variety of kabuli chickpea. It has been instrumental in extending kabuli chickpea cultivation to short-season environments of India and its neighboring country Myanmar. This short-duration variety covers over 50% of the chickpea area in Myanmar (Than *et al.*, 2008). Several short-duration high yielding varieties of chickpea, both in desi (*e.g.* ICCC 37, JG 11, JG 130, JAKI 9218) and kabuli (KAK 2, JGK 1, JGK 2, Vihar) types, have been developed which have helped in expanding chickpea area in central and southern India.

Further advancements have been made in breeding for super-earliness in chickpea. Two super early lines, ICCV 96029 and ICCV 96030 of desi chickpea were developed that mature in 75 to 80 days in southern India (Kumar and Rao 1996). The farmers prefer to grow early podding cultivars for vegetable purpose as early delivery to the market fetches higher price.

Experiments showed that super-early chickpeas can be grown after harvest of rice and before planting of wheat as a short duration catch crop for vegetable purpose (Sandhu *et al.*, 2007).

One of the biggest success stories for chickpea is the revolution in chickpea production in Andhra Pradesh due to adoption of short-duration cultivars (Figure 4). There has been a 9.3-fold increase in production (from 95,000 to 884,000 t) during the past 10 years (1999/00 to 2008/09) because of 3.8-fold increase in area (102,000 to 602,000 ha) and 2.4-fold increase in yield levels (583 to 1407 kg ha^{-1}). About 80% of the chickpea area in Andhra Pradesh is cultivated with improved short-duration varieties (*e.g.* JG 11, JAKI 9218, ICCC 37, KAK 2 and Vihar) developed through partnership between ICRISAT and Indian NARS. The desi chickpea variety JG 11 is presently the most popular variety in Andhra Pradesh grown in about 70% of the chickpea area. Andhra Pradesh once considered a low productive state for chickpea due to warm and short-season environments now has the highest yield levels in India.

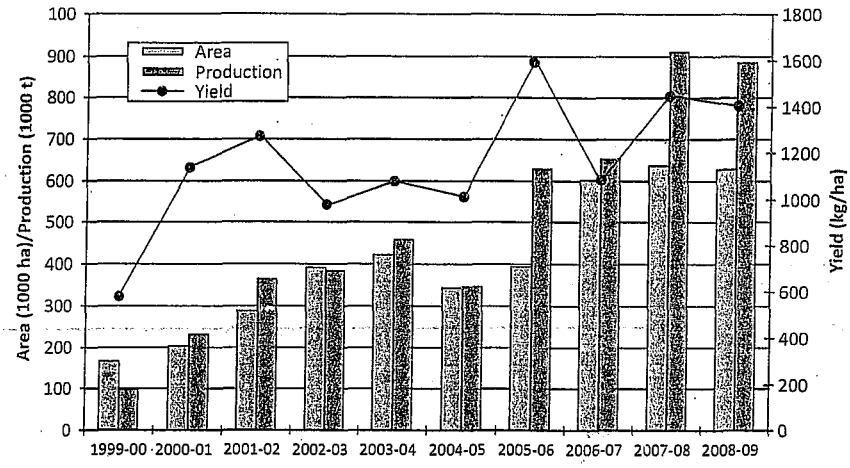

FIGURE 4: Increase in chickpea area, yield and production in Andhra Pradesh.

Responsive to high input conditions

The All India Coordinated Research Project (AICRP) on chickpea had separate trials on evaluation of varieties for high input conditions. One variety DCP 92-3 was specifically released for irrigated conditions of northwest plain zone of India.

Efforts are being made to develop genotypes with short internodes and erect growth habit as such plant type may resist excessive vegetative growth in high input conditions. Two brachytic mutants, one spontaneous (E100 YM) and one induced (JGM 1), with short internodes and compact growth habit have been used in ideotype breeding and promising progenies with compact growth habit have been obtained (Lather 2000, Gaur *et al.*, 2008b).

Tolerance to abiotic stresses

Drought tolerance

Grain yield under drought condition is commonly used as selection criteria for drought tolerance in chickpea. However, heritability of yield is low and it often further declines under stress

conditions. Therefore, selection on the basis of grain yield per se for improved performance under drought condition may not always be effective. Extensive multilocation evaluation for 2-3 years in replicated yield trials is needed to improve selection efficiency. In addition to grain yield, traits associated with drought tolerance and having high heritability can be used as selection criteria for drought tolerance.

Deep and vigorous root system is expected to play an important role in drought avoidance in receding soil moisture conditions by improving water availability to the plant through more efficient extraction of available soil moisture. As it is difficult to select for root traits in a segregating population, marker-assisted selection is being used. Molecular markers have been identified for a major a genomic region that accounts for one-third of the variation for root weight as well as root length (Chandra *et al.*, 2004). Marker-assisted backcross (MABC) breeding method has been successfully used to introgress this genomic region into three cultivars, including JG 11 (Gaur *et al.*, 2011).

Efforts are also being made to develop transgenics with enhanced drought tolerance. Transgenics containing the dehydration response element DREB 1A under the control of a stress-inducible promoter 'rd29A' and other transgenics with P5CSF-129A gene, which increases proline accumulation in the plant and improves tolerance to osmotic stress, have been developed at ICRISAT. Some of the transgenic events were found to be superior to the parent cultivar for transpiration efficiency, photosynthetic activity, stomatal conductance and total transpiration under water limited conditions. These are being studied further and efforts are also being made to generate additional transgenic events.

Tolerance to temperature extremes

Large genetic variation exists for heat tolerance in chickpea (Krishnamurthy *et al.*, 2011). A partnership project of ICRISAT and Indian NARS has identified several chickpea cultivars/breeding lines (*e.g.* ICCV 07104, ICCV 07105, ICCV 07110, ICCV 07115, IPC 2006-99) with high level of heat tolerance. One heat tolerant cultivar JG 14 (ICCV 92944) has been released by Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur for late-sown conditions. This cultivar is being evaluated in various late sown conditions including rice-fallows. Several breeding lines (*e.g.* ICCV 88502, ICCV 88503, ICCV 88506, ICCV 88510 and ICCV 88516) that set pods at lower temperatures were developed at ICRISAT (ICRISAT, 1994; Srinivasan *et al.*, 1998). These have been used extensively as sources of cold tolerance in India and several other countries. Similarly, researchers at IARI have developed several genotypes (BGD 112 green, BG 1101, BGD 1005, PUSA 1108, DG 5027, DG 5036 and DG 5042) that produce high biomass and continue to produce flowers and set pods between 8°C and 10°C. Restriction fragment length polymorphism (RFLP) markers and converted to sequence characterized amplified region (SCAR) markers were used successfully to select chill-tolerant progeny from a cross between Amethyst and ICCV 88516 (Millan *et al.*, 2006).

Salinity tolerance

There is low genotypic variation for salinity tolerance in chickpea. Some genotypes with low or moderate levels of salinity tolerance have been identified. Karnal Chana 1 (CSG 8962), a desi chickpea variety has been released for salt affected soils of the north-west plain zone and can be grown on soils with moderate levels of salinity (ECe ranging from 4 to 6 dS/m). Recent screening for salinity tolerance at ICRISAT identified several lines that gave higher yield than the salinity tolerant cultivar Karnal Chana 1 under saline condition (Vadez *et al.*, 2007, Krishnamurthy *et al.*, 2011). These new sources of salinity tolerance have opened further opportunities for enhancing salinity tolerance in chickpea

Resistance to biotic stresses

Resistance to fusarium wilt

Development of *fusarium* wilt resistant cultivars is one of the greatest success stories of chickpea breeding. The availability of highly resistant sources, simple and effective screening techniques and availability of good wilt sick fields at several research centers have contributed to the success in development of chickpea cultivars with very high levels of resistance to *fusarium* wilt. Four races (1 to 4) of *fusarium* wilt exist in India (Haware and Nene 1982) and cultivars have been developed that are resistant to three (*e.g.* JG 315, JG 74) or all the four races (*e.g.* GL 87078 and GL 87079). Resistance to *fusarium* wilt is must for release of any chickpea variety in India.

Resistance to ascochyta blight (AB)

Resistance to ascochyta blight is controlled by several genes (major and minor) and the inheritance is quantitative in nature. The ascochyta blight pathogen is highly variable as pathotypes carrying different mating type alleles can coexist in the same field and random mating may occur between different mating types. Genetic recombination in the fungus may contribute to genotypic diversity to adapt and infect newly introduced resistant cultivar (Pande *et al.*, 2005). Methods for ascochyta resistance screening have been standardized (Pande *et al.*, 2010). Extensive efforts have been made to screen the chickpea germplasm available at ICARDA and ICRISAT to identify sources of resistance to ascochyta blight. Several accessions with moderate to high levels of resistance were identified. Some accessions (ILC 72, ILC 191, ILC 3279 and ILC 3856) showed resistance in eight countries (Singh *et al.*, 1984). Several accessions (ILC 200, ICC 4475, ICC 6328, ILC 6482 and ICC 12004) showed resistance to six races in repeated greenhouse and field screening (Singh and Reddy 1993).

As resistance to ascochyta blight is controlled by several genes, ICRISAT has concentrated on enhancing levels of AB resistance by accumulating resistance genes from different sources. Some progenies from multiple crosses (*e.g.* ICCV 04512, ICCV 04514 and ICCV 04516) have shown high levels of resistance to multiple isolates (Gaur and Gowda, 2005). Several chickpea cultivars with moderate to high levels of resistance have been released in India. These include PUSA 261, PBG 1, GNG 469, Gaurav, Himchal Chana 1, and Himchal Chana 2.

Resistance to botrytis grey mold (BGM)

A major constraint in breeding for BGM resistance is the non-availability of high level of resistance in chickpea germplasm (Pande *et al.*, 2006). Despite screening large number of germplasm and breeding lines at ICRISAT, no highly resistant line was identified. However, genotypes with moderate levels of resistance have been identified. One accession (ICC 14344) has been released as 'Avarodhi' for commercial cultivation in India. High level of resistance to BGM has been observed in wild *Cicer* species including *C. echinospermum* and this source of resistance needs to be exploited in breeding programs. Plant types that maximize canopy aeration, have upright branching coupled with good lodging resistance are important to host resistance.

Resistance to pod borer

It has been not possible to develop varieties with high levels of resistance to pod borer due to non-availability of sources with high levels of resistance. ICC 506 EB, which showed a mean of 8.6% pod damage as against 29.9% in the popular cultivar Annigeri, is probably the best

available source of resistance in the cultivated chickpea (Lateef and Pimbert, 1990). Several tolerant lines identified by ICRISAT and the national chickpea program have been used in breeding programs. However, no released variety has high level of resistance to pod borer. Higher levels of resistance were observed in some wild species (Sharma *et al.*, 2005). Efforts are being made to combine the non-preference (antixenosis) mechanism of resistance identified in the cultigen (*e.g.* ICC 506 EB) and antibiosis mechanism of resistance identified in *C. reticulatum.*

Transgenic technology is being exploited to develop chickpea cultivars with high levels of resistance to pod borer. Transgenic chickpea produced using the truncated native *Cry1Ac* gene showed effective resistance to *Helicoverpa* causing more than 80% insect mortality (Sanyal *et al.*, 2005). ICRISAT and other national institutes have developed transgenics utilizing *Bacillus thuringiensis's Cry1Ab* and *Cry1Ac* genes. Insect bioassays and evaluation of transgenics in contained field trials are in progress.

Marker-preferred seed traits

The current chickpea breeding programs are laying greater emphasis on development of cultivars with market preferred seed traits. The varieties in desi type typically have seed size between 18 to 25 g/100-seed. In kabuli type, all recent varieties have seed size more than 30 g/100-seed. There have been concentrated efforts on development of extra-large kabuli varieties considering the preference of consumers and the demand by farmers. A special project under Integrated Scheme of Oilseed Pulses and Oil Palm (ISOPOM) was launched by Indian Chickpea Research Programs in partnership with ICRISAT to develop kabuli chickpea varieties with extra-large seed (>50 g/100-seed). Two cultivars (Phule G 0517 and IPCK 2) and several advanced breeding lines with extra-large seed have been developed through this project.

10. FUTURE THRUST AREAS

Chickpea cultivars suited to mechanical harvesting

The farmers in India are gradually enhancing mechanization of farm operations for improving efficiency and reducing cost of cultivation. Agricultural operations like sowing of many crops, including chickpea, are mostly done by seed drills and the use of combine harvesters is becoming common practice now in wheat and rice. The farmers, particularly in Andhra Pradesh, are demanding chickpea cultivars suited to mechanical harvesting. The current chickpea cultivars are not suited to mechanical harvesting because the plant height is not adequate and the branches are close to ground due to semi-spreading growth habit. Development of chickpea cultivars with 30 to 40% more height than the existing cultivars and semi-erect to erect growth habit will make the cultivars suited to mechanical harvesting. Several tall breeding lines with semi-erect to erect growth habit are already available at ICRISAT and Indian Chickpea Research Programs which can be exploited for development of cultivars suited to mechanical harvesting.

Chickpea cultivars tolerant to herbicides

Developing herbicide tolerant varieties can reduce the cost of cultivation significantly. Chickpea is sensitive to herbicides and manual weeding is currently the only option for weed control. Weeds, if left uncontrolled, can reduce chickpea yield considerably. For effective control of weeds in chickpea both inter-row and intra-row weeding is necessary under close planting conditions. Thus, weed management in chickpea is becoming expensive and in some cases uneconomical due to rising labor cost. Herbicide-tolerant cultivars help in controlling weeds economically and also facilitate no-till methods, which help preserve topsoil. Therefore,

identifying sources of variation for herbicide tolerance and development of herbicide tolerant cultivars in chickpea will result in increased profits for the chickpea farmers.

Nutrient rich chickpea

Little efforts have been made up until now to breed for high protein chickpea cultivars even though there is genetic variation (14 to 28%) in cultivated germplasm. The protein content of most of the currently available cultivated varieties generally ranges between 20-22%. The high protein germplasm accessions already identified can be exploited for development of high protein varieties. There is no or very little information available on the extent of genetic variability available for iron and zinc in the chickpea germplasm. There is an urgent need to assess the genetic variability available for iron and zinc in the chickpea germplasm so that suitable breeding strategies can be developed for further enhancing iron and zinc content in chickpea.

The only negative factor related to chickpea consumption is more flatulence which is caused by a higher concentration of raffinose family oligosaccharides (RFOs). The RFOs are nearly ubiquitous in the plant kingdom, but are more abundant in legume seeds especially chickpeas. Despite numerous well-proven health benefits, RFO-induced flatulence reduces the acceptance of chickpea. To date there is no available information on the extent of genetic variability present in chickpea germplasm for RFO content. Thus, there is need to identify and develop chickpea cultivars with low levels of RFOs in seeds to address the flatulence problem caused by consumption.

11. MAJOR CROP IMPROVEMENT RESEARCH STATIONS

International Crop Research Institute for the Semi-Arid Tropics (ICRISAT)

ICRISAT is one of the 15 consortium members of the Consultative Group on International Agricultural Research (CGIAR). It was established in 1972 at Patancheru, Andhra Pradesh, India. ICRISAT holds the world's largest collections (20,140 accessions) of chickpea genetic resources. ICRISAT has so far distributed over 110,000 samples of chickpea to the scientists in 84 countries. Fifteen germplasm lines supplied by ICRISAT have been released directly as cultivars in 13 countries. The breeding materials supplied by ICRISAT have led to release of 77 chickpea cultivars in 10 countries. Of these, 34 cultivars have been released in India. ICAR-ICRISAT collaborative chickpea varieties account for one-third of the indent of chickpea breeder seed in India.

International Center for Agricultural Research in the Dry Areas (ICARDA)

ICARDA is also one of the consortium members of the CGIAR. It was established in 1977 with its main research station and offices based in Aleppo, Syria. ICARDA is responsible for the improvement of kabuli chickpea in the Central and West Asia and North Africa (CWANA) region. The gene bank of ICARDA has over 13,800 accessions of chickpea, including 260 accessions of wild species. More than 100 kabuli varieties have been developed in about 30 countries from the material developed at ICARDA.

All India Coordinated Research Project (AICRP) on Chickpea

Chickpea research in India was coordinated through All India Coordinated Pulses Improvement Project (AICPIP) which was established in in 1967. During VIII Plan the, AICPIP was trifurcated into three projects *i.e.* Chickpea, Pigeonpea and MULLaRP to provider greater focus

to these pulses. Thus, a separate AICRP on Chickpea came into existence from 1993. AICRP on Chickpea currently has four lead centers (Bengaluru, Rahuri, Jabalpur and Durgapura), five main centers (Junagadh, Hisar, Sehore, Ludhiana and Sriganganagar), 15 sub-centers (Nandayal, Shillongani, Dholi, Mokama/Sabour, Raipur, Kanke, Samba, Dharwad, Badnapur, Imphal, Kota, Faizabad, Jhansi, Pantnagar and Berhampore) and 34 Volunteer Centers spread all over India. AICRP provides leadership and coordination to chickpea research in India. Research efforts made through National Agricultural Research System (ICAR and SAUs) have led to release of more than 125 chickpea varieties which are adapted to varying agro-climatic conditions. These varieties have in built resistance against key biotic stresses prevalent in the chickpea growing areas. From time to time, specific trial under the aegis of AICRP-Chickpea were constituted to meet the specific target needs such as large seeded desi and kabuli types, extra-large seeded kabuli types, adaptation to late sown condition, high input responsiveness and salt tolerance, resistance to *Fusarium* wilt and Ascochyta blight.

Indian Institute of Pulses Research (IIPR)

IIPR is a national institute established by ICAR at Kanpur to carry out basic strategic and applied research on major pulse crops. Besides generating basic knowledge and material, the Institute also develops appropriate production and protection technologies, production and supply of breeder seeds of improved varieties, demonstration and transfer of technologies and strategic coordination of pulse research through wide network of testing centers across the country. Five chickpea varieties have been developed by IIPR, which include two desi type (DCP 92-3, IPC 97-67) and three kabuli type (IPCK 2002-29, IPCK 2004-29, IPCK 2).

Indian Agricultural Research Institute (IARI)

The Indian Agricultural Research Institute is the country's premier national Institute for agricultural research, education and extension. It has the status of a 'Deemed-tobe-University' under the UGC Act of 1956, and awards M.Sc. and Ph.D. degrees in various agricultural disciplines. The institute was originally established in 1905 at Pusa (Bihar) and later shifted to New Delhi in 1936 after a major earthquake damaged the Institute's building at Pusa. Thus, the Institute's popular name 'Pusa Institute' traces its origin to the establishment of the Institute at Pusa. IARI has had a strong research program on chickpea improvement and significantly contributed to development of chickpea cultivars. Several chickpea varieties have been developed by IARI, including Pusa 256, Pusa 329, Pusa 362, Pusa 372, Pusa 391, Pusa kabuli 1003, Pusa Chamatkar (BG 1053), Pusa 1088, Pusa 1103 and Pusa 1105.

QUESTIONS

1. What are the centers of diversity for chickpea?
2. What are the morphological and economic use differences between desi and kabuli chickpeas?
3. Why excessive growth is a problem in long season environments?
4. Explain the genetic behavior of flowering time in chickpea?
5. Who are the major exporter and importer of chickpea seed in the world?
6. Why are hybrids not developed in chickpea?
7. What are the major bottlenecks in breeding for resistance to pod borer?
8. Why terminal drought and heat stresses are major constraints to chickpea production in India?
9. How has ascochyta blight become a less important disease of chickpea in India?

10. How does marker-assisted selection improve precision and efficiency of chickpea breeding?

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