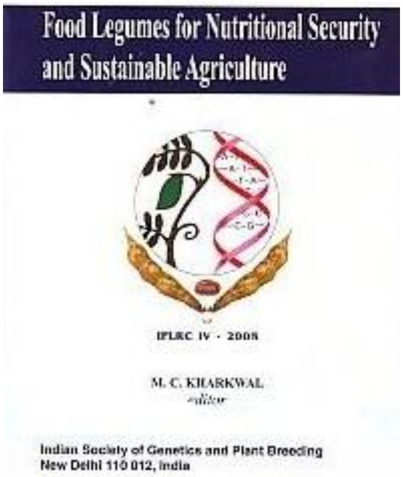

"Breeding chickpea for early phenology: perspectives, progress and prospects,"

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Breeding Chickpea for Early Phenology: Perspectives, Progress and Prospects

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ABSTRACT

Chickpea (*Cicer arietinum* L.) is currently grown in over 50 countries representing a wide range of environments and cropping systems. Phenology (time to flowering, podding and maturity) is an important component of crop adaptation in these environments. Crop maturity 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 drought or temperature extremities at the end of season (pod filling stage of the crop). About 73% of the global chickpea area is in South and Southeast Asia where chickpea is largely grown rainfed in the post-rainy season on receding soil moisture and often experiences terminal drought and heat stresses. Early phenology is also important in autumn-sown rainfed crop in Mediterranean-type environments for escape from terminal drought, as in Australia; and in summer-grown crop in the temperate environments for escape from frost at the end of season, as in Canada. Early phenology is also needed for promotion of chickpea to rice-fallows and other late sown conditions of south Asia. Hence, development of early maturing cultivars is one of the major objectives in chickpea breeding programs of International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India and in several countries, including India, Myanmar, Bangladesh, Ethiopia, Australia and Canada. Several short-duration cultivars with resistance to fusarium wilt have been developed which have made significant impacts on enhancing chickpea area and production in central and southern India, Myanmar and Ethiopia. Efforts are being made to combine earliness with resistance to ascochyta blight and chilling tolerance for enhancing adaptation of chickpea to short-season Mediterranean regions and temperate environments. Early and extra-early cultivars are expected to play key role in expanding chickpea area in new niches where available crop growing season is short.

Introduction

Chickpea (*Cicer arietinum* L.), the third most important food legume globally, is grown on over 10 m ha across 51 countries (FAOSTAT, 2007) from equatorial tropics to the temperate northern latitudes (50^0N). The crop is known to be photo-thermo sensitive and its maturity ranges from 80 to 180 days depending on genotype, soil moisture, time of sowing, latitude and altitude. Lower temperatures, shorter photoperiods and optimal soil moisture, individually or in combinations, help in extending growth period, while higher temperatures, longer photoperiods and moisture stress conditions are known to shorten all developmental phases thereby reducing the crop duration (Summerfield et al., 1990). In a study conducted by ICRISAT mean number of days to 50% flowering in a set of 25 genotypes were 51 at Patancheru (18ºN), 76 at Gwalior (26°N) and 96 at Hisar (29ºN) (Kumar and Abbo 2001). Genotypic discrimination in terms of flowering and maturity are wide apparent in warmer short-season environments than in cooler long-duration environments (Saxena, 1984). Several early flowering accessions of desi and kabuli types have been identified from germplasm and most of these originated from India, Ethiopia, Mexico and Iran (Pundir et al., 1988; Upadhyaya et al., 2007). These are expected to be less sensitive or insensitive to photoperiod and/or temperature differences.

Phenology (time to flowering, podding and maturity) plays critical role in adaptation of chickpea cultivars to different environments (Berger et al., 2004, 2006). Early phenology is a key trait for adaptation of chickpea to short-season environments as it helps crop to escape from end-of-season stresses (drought, temperature extremities). This paper provides a brief account of the progress made in genetic studies and breeding for early phenology and future prospects of breeding and deploying cultivars with early phenology in target environments and cropping systems.

Genetics of flowering

Flowering time or days to flowering (number of days from sowing to appearance of first flower) can be recorded with high precision and provides fairly good indication of succeeding phenological traits (time of podding and maturity). Thus, most genetic studies in the past have concentrated on flowering time and suggest that it is under control of few genes. Gumber et al. (1996) provided preliminary evidence that two duplicate genes in homozygous recessive state cause early flowering in ICCV 2 and accounted for 35 days difference in flowering between ICCV 2 and late flowering parents GL 769, BG 276, and PGK 45. Later, Kumar and van Rheenen (2000) reported a major gene (designated *efl-1*) for flowering time in ICCV 2 from its cross with a medium duration cultivar JG 62. They studied recombinant inbred lines (RILs) of the cross ICCV 2 x JG 62 and observed bimodal distribution with nearly equal peaks, one peak corresponding with ICCV 2 and the other with JG 62. They suggested that other minor genes were also segregating in this cross. Development of super early lines ICCV 96029 (which flower in about 24 days at Patancheru) from a cross between two early lines, ICCV 2 and ICCV 93929 (which flower in 30 to 32 days at Patancheru), further indicated involvement of more than one gene in controlling flowering time (Kumar and Rao, 1996; Kumar and Abbo, 2001). ICCV 96029 inherited *efl-1* from ICCV 2 and at least one additional gene affecting early flowering from ICCV 93929.

ICC 5810 (Harigantras), a black-seeded landrace from central India, has been another source of early flowering. This accession is relatively day length or photoperiod insensitive (Roberts et al., 1985) and flowered about two months earlier than the cultivar Hadas (days to flower 115 to 140) at Rehovot, Israel (Or et al., 1999). Study of F_2 segregation for days to flowering suggested that differences in days to flowering between ICC 5810 and Hadas are due to a major gene, designated *ppd* (photoperiod dependent) (Or et al., 1999). Recent experiments conducted at ICRISAT suggest that *efl-1* gene of ICCV 2 (also present in ICCV 96029) is not allelic to *ppd* gene of ICC 5810 (P.M. Gaur, unpublished results).

Two early flowering lines, 272-2 and 298T-9, derived from crosses that involved ICCV 96029 as one of the parents, were studied for inheritance of flowering time in Western Canada that has a short-season temperate environment. Crosses of these lines with late flowering Canadian cultivars ‘CDC Anna’ and ‘CDC Frontier’ segregated for two major genes and interaction between these genes was mainly an additive x additive type (Anbessa et al., 2006a). This study further supports presence of two major genes for flowering time in ICCV 96029.

Estimates of heritability for time to flowering, time to first pod maturity, percent pod maturity at four months after planting and time to maturity suggest that all these phenological traits have high heritability (Anbessa et al., 2006b). Thus, the gain from selection for these traits is expected to be high provided high genetic variability is present in the base population.

Efforts have also been made to map major genes for flowering time. A major QTL for flowering time was identified from ICCV 2 x JG 62 RILs and mapped between simple sequence repeat (SSR) markers TA 57 and TA 127 on linkage group 3 (LG 3) (Cho et al., 2002). This QTL must be corresponding to *Efl-1* locus identified by Kumar and van Rheenen (2000) from the same cross. Two QTLs for flowering time were identified from study of Hadas x ICC 5810 RILs (Lichtenzveig et al., 2006). One QTL accounted for 53 to 56% of variation and mapped on LG1 between the markers H1F022 and GA 40. This QTL may correspond to the major flowering time gene *ppd* identified from this cross by Or et al. (1999). The second QTL that accounted for 18 to 22% of variation was mapped on LG 2 between the markers H 4B09 and H1 B06. The locations of QTLs corresponding to *efl-1* and *ppd* on different linkage groups (LG 3 and LG 1, respectively) further support the observation that major early flowering genes in ICCV 2 and ICC 5810 are different.

Breeding chickpea for early phenology

Semi-arid tropical environments

A large area under chickpea production exists is in the semi-arid tropics (SAT) where chickpea is mainly grown in post-rainy season on residual soil moisture without irrigation. The crop most often experiences moisture and heat stresses at reproductive stage. Early maturity helps to escape from these stresses and is a key trait for adaptation of chickpea to SAT.

India is the largest chickpea producing country with a share of about 64% in global chickpea production (FAOSTAT, 2007). Chickpea is grown in an area of about 6.7 m ha from 32°N in northern India with cooler long-season environment to 10°N in southern India with warmer short-season environment. There has been a large shift in chickpea area from north to central and southern India, mainly because of expansion in area under irrigation and wheat cultivation in northern India. During 1964-65, the chickpea area in northern and north-eastern states (Punjab, Haryana, Uttar Pradesh and Bihar) was 5.15 m ha which has reduced to 0.96 m ha during 2005-06. However, chickpea area in central and southern states (Madhya Pradesh, Maharashtra, Karnataka and Andhra Pradesh) increased from 2.05 m ha to 4.67 m ha during the same period. This shift in area from cooler long-season environments to warmer short-season environments has further enhanced importance of short-duration cultivars.

Fusarium wilt caused by *Fusarium oxysporum* f. sp. *ciceri* is the most important disease of chickpea in SAT where chickpea growing season is dry and warm. Thus, chickpea cultivars for SAT must have resistance to fusarium wilt. Developing early maturing cultivars with high resistance to fusarium wilt has been a major objective in ICRISAT's chickpea breeding program. The collaborative efforts of ICRISAT and national agricultural research systems (NARS) in several SAT countries, including India, Myanmar, Bangladesh, Ethiopia and Sudan, have led to development of several high yielding, early-maturing and fusarium wilt resistant cultivars.

Historically kabuli chickpea area in SAT was negligible, as the available kabuli cultivars were late maturing and more suited to cooler long-season environments. ICRISAT-NARS collaborative efforts have led to development of several early maturing kabuli chickpea cultivars which are well adapted to SAT environments, e.g. ICCV 2 (ICRISAT, 1990), PKV Kabuli 2 or KAK 2 (Zope et al., 2002), JGK 1 (Gaur et al., 2004) and Chefe (Ketema et al., 2005). Availability of early maturing cultivars has made possible production of kabuli chickpea profitable in the SAT environments. The kabuli chickpea area has expanded rapidly in Myanmar, Southern and Central India, and Ethiopia. It is interesting to note that Myanmar, which has very short-growing season like southern India, now has about 60% of chickpea area under kabuli type (Than et al., 2007). This change was brought by the extra-early cultivar ICCV 2 (released as Yezin 3 in Myanmar), which has witnessed very high rate of adoption and is now grown in 55% of chickpea area (Than et al., 2007).

In desi type chickpea also, several cultivars with early maturity and high resistance to fusarium wilt are available. Some of the most popular cultivars in SAT environments include ICCC 37 and JG 11 (ICCV 93954) in southern India, ICCV 88202 (Yezin 4) in Myanmar and Mariye in Ethiopia.

Adoption of early maturing desi and kabuli chickpea cultivars along with suitable crop production packages has led to enhancement of chickpea production in some SAT regions. For example in Myanmar during the past decade (1995/96 to 2004/05), the chickpea area has increased by 23% (from 166,000 to 205,000 ha), yields have almost doubled (from 588 to 1171 kg ha^{-1}), and production has increased 2.6 times (from 92,000 to 239,000 ha) (Than et al., 2007). During 2005, Myanmar was the fifth largest chickpea producing country after India, Pakistan, Turkey and Iran (FAOSTAT, 2007).

A chickpea revolution has taken place in Andhra Pradesh, a southern state of India where ICRISAT's headquarter and chickpea improvement program are based. The chickpea area has increased from 106,000 ha in 1996/97 to 384,000 ha in 2005/06. The most important development is the enhancement in yield from 853 to 1,596 kg ha^{-1} during this period. Increase in area and yield levels has led to 7-fold increase in chickpea production (90,000 to 629,000 t). Andhra Pradesh once considered to be a low productive state for chickpea due to warmer and short-season environments now has the highest chickpea yields in India.

Mediterranean and temperate environments

In the Mediterranean environments also the dryland chickpea crop are exposed to high evaporative demand and water stress during the reproductive stage. Thus, early flowering/podding chickpea cultivars may realize higher yield in winter-season chickpea by expanding duration of reproductive period (Kumar and Abbo, 2001). Early maturity is also important in temperate environments, as in Canada, for escaping end-of-season frost. Late maturity is one of the major constraints to chickpea production in Canada as the chickpea growing season is short (110-120 days) and late maturing cultivars suffer severe losses in grain yield and quality due to frost (Warkentin et al., 2003).

Ascochyta blight caused by *Ascochyta rabiei* (Pass.) Lab. is the most important disease of chickpea in Mediterranean and temperate environments. The disease is favored by low-temperatures (10-20^{o} C) and moderate to high relative humidity (>60%) (Pande et al., 2005). Chilling temperature is also an important abiotic constraint in many regions such as southern Australia as it delays pod formation in sensitive cultivars by affecting development and function of reproductive structures (Croser et al., 2003: Clarke and Siddique, 2004).

Most sources of ascochyta blight resistance identified in desi and kabuli chickpea germplasm are late maturing. It may be so because these germplasm originated from cooler long season environments where ascochyta blight frequently occurs. There are variable reports on relationship between phenology and resistance to ascochyta blight in chickpea. A negative correlation between days to flower and resistance to ascochyta blight was reported by Lichtenzveig et al. (2002). Later, this group identified one of the ascochyta blight resistance QTLs linked with one of the loci for time of flowering (Lichtenzveig et al., 2006). However, in another study this group found no relationship between phenology and ascochyta blight resistance and suggested no constraints in combining ascochyta blight resistance with early phenology (Bonfil et al., 2006). There are reports on developing early maturing ascochyta resistance lines (Singh and Reddy, 1996; Clarke et al. 2004; Bonfil et al. 2007). There are also reports on successful efforts on inducing mutations for early phenology in late maturing ascochyta blight resistant lines. For example, two induced mutants from ascochyta blight resistant line FLIP 90-73C flowered and matured 25 to 30 days earlier than the parental line (Omar and Singh, 1995).

The chickpea breeding program of Western Australia has successfully combined early maturity, moderate ascochyta blight resistance and chilling tolerance in two desi chickpea cultivars, WACPE 2075 (Sonali) and WACPE 2095 (Rupali) (Clarke et al., 2004). Pollen selection for chilling tolerance at hybridization was successfully used to introgress chilling tolerance from ICCV 88516 to Australian sensitive cultivars Amethyst and Tyson (C 235). Resistance to Ascochyta blight was introgressed from FLIP 84-15C. WACPE 2075 and WACPE 2095 podded 14 days earlier than the standard early cultivar Sona and chilling tolerant parent ICCV 88516 and 27 days earlier than the sensitive parental cultivars Amethyst and Tyson. The threshold mean daily temperature for pod formation in these lines was 10-12^{o}C as compared to 14-15^{o}C in Sona, Tyson and Amethyst (Clarke et al., 2004).

The chickpea breeding program in Canada has a major focus on development of ascochyta blight resistant cultivars that can mature early in temperate environments (Warkentin et al., 2003). Several specific traits, including early flowering, double podding and short internode length, were evaluated for their ability to induce earliness in Western Canada. The incorporation of short internode and double podding traits was considered as these are expected to hasten pod filling and consequently maturity by increasing reproductive sinks (more number of reproductive nodes and pods per plant) (Warkentin et al., 2003; Anbessa et al., 2006 a,b). Another trait that could be useful for introducing early maturity in chickpea in cool and wet conditions is determinate/semi-determinate growth habit, which has been successfully exploited in several other food legumes (Gaur et al. 2007a). Determinate growth habit was successfully induced in chickpea but the mutant was sterile (van Rheenen et al., 1994). However, it does not rule out possibility of inducing fertile determinate growth habit mutants.

Specific niches for early chickpea cultivars

Cultivation of chickpea in rice-fallows and other late sown conditions

Chickpea is subjected to late sowing in certain situations, such as delayed maturity of preceding crop, delay in field preparation due to excessive soil moisture, increase in cropping intensity (taking three crops per year, e.g. rainy season crop → short duration catch crop → chickpea). The late sowing of chickpea leads to reduction in the duration of crop growing season. Considerable area is available for chickpea cultivation under late sown conditions in northern India and provides an opportunity for expanding chickpea area, which is very much needed for diversification of rice-wheat cropping system (Chaturvedi and Ali, 2004). Early maturing cultivars with heat tolerance will be required for these conditions. Some cultivars (e.g. BG 372, KPG 59 and Pant G 186) have been released in India for late sown conditions and are becoming popular in Indo-Gangetic Plains. A number of early maturing advanced breeding lines developed at IIPR-Kanpur gave higher yield than the early maturing lines ICCV 96029 and ICC 10429 and the standard cultivar BG 372 under late sown condition (sowing in end of December) (S.K. Chaturvedi, unpublished results).

About 14 m ha in South Asia (11.6 m ha in India, 2.1 m ha in Bangladesh, 0.4 m ha in Nepal and 0.14 m ha in Pakistan) remains fallow in winter season after harvest of rainy season rice due to lack of irrigation (Subbarao et al., 2001). These rice-fallows offer enormous potential for expansion of chickpea area in South Asia. The studies conducted on promotion of chickpea in rice-fallows of Bangladesh and India indicate that short-duration chickpea cultivars have better chances of success in rice-fallows as the crop often experiences drought and heat stresses at the end of season (Musa et al., 2001; Gaur and Gowda, 2005). A set of short-duration desi and kabuli cultivars was subjected to farmer participatory varietal selection in five states of India for identifying suitable cultivars for rice-fallows. The farmers at all locations preferred short-duration kabuli types (ICCV 2, PKV Kabuli 2 and JGK 1). The recent experiments at ICRISAT suggest that kabuli types perform better than desi types in late sown conditions, probably due to improved heat tolerance (Gaur et al., 2007b). This may be the reason for better performance of kabuli types in rice-fallows and this needs further studies.

Though early maturity is an important trait for adaptation of chickpea to rice-fallows and late sown conditions, other traits for specific adaptation (e.g. ability to germinate and establish under high moisture and comparatively anaerobic conditions for sowing of chickpea with zero or minimum tillage after harvest of rice) should also need to be considered. There is a need for a focused breeding effort in chickpea to develop specific cultivars adapted to these conditions.

Chickpea as a fresh grain vegetable crop

The immature green grains of chickpea are used as vegetable or snack (raw or roasted) in many countries. The farmers prefer to grow early podding cultivars for vegetable purpose as early delivery to the market fetches higher price. The staggered planting of early podding cultivars can ensure availability of fresh pods consistently for a longer period.

In northern India, the green grains are available for a short period as the available cultivars are late maturing and take too long to initiate podding. Early flowering and low temperature tolerance traits are required in such cultivars for early podding in this region. Several experiments were conducted on evaluation of super early and cold-tolerant lines ICCV 96029 and ICCV 96030 for their suitability for cultivation in northern India for vegetable purpose. ICCV 96029 could set pods during cold months and produce 3.6 t ha^{-1} green pods in 70 days after sowing while the control cultivar PB1 took more than 120 days to initiate podding (Sandhu et al., 2002). Though the early podding lines could make available green grains for a longer period, the adoption of these lines was restricted primarily due to their susceptibility to fusarium wilt and pale green color of immature grains. Thus, efforts have been made to improve these traits of super-early lines (Sandhu et al., 2007). The improved super-early lines are being evaluated in India at ICRISAT-Patancheru, PAU-Ludhiana and IIPR-Kanpur.

Concluding remarks

Phenology is one of the key traits for adaptation of chickpea to different cropping systems, soil environments and climatic conditions. Early phenology helps to escape end-of-season stresses, such as drought and extremes of temperatures, and provides opportunity for growing chickpea in short windows of crop-season available. Considerable progress has been made in development of early and extra-early chickpea cultivars in both desi and kabuli types. Several cultivars with high yield potential, early maturity and resistance to fusarium wilt are available and their adoption is showing impact on enhancement of chickpea production in some short-season SAT environments. There is also progress in combining early phenology traits with resistance to ascochyta blight and chilling tolerance. However, the level of ascochyta blight resistance in these lines remains low and need to be enhanced. There is enormous potential for expanding chickpea area in South Asia by making available cultivars and production technologies suitable to specific niche areas, e.g. rice-fallows and various late sowing conditions. The development of super-early chickpea lines has further expanded the potential role of chickpea in several new farming systems.

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