Drought and heat tolerance in chickpea

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Abstract: Chickpea is largely grown rainfed on residual soil moisture after the rainy season. Terminal drought is a major constraint to chickpea production, particularly in the semi-arid tropics. Similarly, exposure of chickpea to heat stress (≥ 35 C) at flowering and podding is known to result in drastic reductions in seed yields. Efforts have been made to develop cultivars that can escape (early maturity) or avoid/tolerate (greater extraction of water from the soil, enhanced water use efficiency) terminal drought. Large genetic variations exist for reproductive stage heat tolerance in chickpea. Many heat tolerant genotypes have been identified through screening of germplasm/breeding lines under heat stress conditions in the field. A heat tolerant breeding line ICCV 92944 has been released for cultivation in Myanmar (as Yezin 6) and India (as JG 14).

Key words: early maturity, root systems, heat stress, marker-assisted breeding

Introduction

Drought and heat are the most serious abiotic constraints to chickpea production globally. It is estimated that drought and heat stresses together account for about 50% of the yield losses caused by abiotic stresses. Chickpea is predominantly grown as a rainfed crop on residual soil moisture stored during the previous rainy season with very less or no rainfall during the growing season. The soil moisture recedes to deeper soil layers with the advancement in crop growth and the crop experiences increasing soil moisture deficit at the critical stage of pod filling and seed development (called terminal drought) (3). Terminal drought is a major constraint to chickpea production in over 80% of the global chickpea area. The extent of terminal drought stress varies depending on previous rainfall, atmospheric evaporative demand, and soil characteristics such as type, depth, structure, and texture.

Heat stress (temperatures > 35 C) at the reproductive stage is increasingly becoming a serious constraint to chickpea productivity because of large shift in chickpea area from cooler long-season environments to warmer short-season environments, increasing chickpea area under late sown conditions due to increasing cropping intensity, and expected overall increase in temperatures due to climate change (5).

Drought tolerance

The mechanisms for adaptation of plants to moisture stress environments are broadly classified into three categories (a) drought escape, (b) drought avoidance (dehydration postponement) and (c) drought tolerance (dehydration resistance). Early phenology (early flowering, early podding and early maturity) is the most important mechanism to escape terminal drought stress. Drought avoidance can be achieved by water uptake by the roots from deeper soil layers, by osmotic adjustment and by reducing water loss (stomata conductance or by reduction in leaf area). Drought tolerance refers to the ability of cells to continue metabolism at low leaf water status.

Figure 1. A chickpea crop severely affected by terminal drought stress

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Chickpea breeding program at ICRISAT has placed high emphasis on development of early maturing varieties for enhancing adaptation of chickpea to environments prone to terminal drought stress (4). There is wide variability for time to flowering in chickpea germplasm, which provides opportunity for developing chickpea cultivars with desired earliness. Several early maturing high yielding cultivars have been developed, e.g., ICCV 2 (Swetha in India, Wad Hamid in Sudan and Yezin 3 in Myanmar), ICCV 92311 (PKV Kabuli 2 or KAK 2 in India) and ICCV 92318 (Chefe in Ethiopia) in kabuli type and ICCC 37 (Kranthi in India), ICCV 88202 (Sona in Australia, Yezin 4 in Myanmar and Pratap chana 1 in India) and ICCV 93954 (JG 11 in India) in desi type. Adoption of early maturing varieties has shown high impacts on enhancement of chickpea area and productivity in short-season environments, e.g. Myanmar and southern India. Super early breeding lines have been developed (e.g. ICCV 96029) which further expand opportunities for cultivation of chickpea in areas and cropping systems where the cropping window available for chickpea is narrow and in specific situations where early podding is highly desired, for example in vegetable purpose crop (used for immature green grains).

Most breeding programs use grain yield under moisture stress for selection of genotypes with enhanced drought avoidance/tolerance. In most cases the material is exposed to terminal drought by growing the crop under rainfed conditions or under rainout shelters. Grain yield is a complex trait controlled by many genes and highly influenced by the environment. Thus, early generation selection for drought avoidance/tolerance is not effective because of low heritability. Lack of uniform spread of soil moisture/drought stress in the field further reduces efficiency of selection. Hence advanced breeding lines are evaluated at multiple locations and over the years.

Several studies in the recent years have focused on identification of morphological and physiological traits associated with drought avoidance/tolerance. Experiments conducted at ICRISAT demonstrated that a prolific root system contributes positively to grain yield under terminal drought conditions (8). Despite well recognized importance of root traits in terminal drought tolerance, limited efforts have been made to breed for improved root traits because the screening for root traits is a destructive and labor intensive process and difficult to use in large segregating populations. Some breeding programs have used genotypes with deep and vigorous root system, such as ICC 4958, as one of the parents in crosses, but selection of breeding lines was invariably for seed yield under water-stress conditions rather than on root traits.

Identification of molecular markers linked to major genes controlling root traits can facilitate marker assisted breeding (MAB) for root traits. There has been considerable progress in development of molecular markers and expansion of genome map of chickpea in recent years (6). A genomic region carrying a transcription factor or quantitative trait loci (QTL) that controls several drought tolerance related traits including some root-traits was located on LG4 from two intra-specific RIL mapping populations (ICC 4958 × ICC 1882 and ICC 283 × ICC 8261) at ICRISAT. This genomic region was introgressed in one desi chickpea cultivar (JG 11) from ICC 4958 (desi type) and in two kabuli chickpea cultivars (KAK 2 and Chefe) from ICC 8261 (kabuli type) using marker-assisted backcrossing (MABC). A set of 20 BC3F4 lines generated from the cross involving JG 11 as recurrent parent was evaluated at 3 locations in India and one each in Kenya and Ethiopia. Several BC3F4 lines giving significantly higher yield than the cultivar JG 11 were identified at each location (7). The initial results from the evaluation of MABC lines are encouraging and suggest the scope of effective use of marker-assisted breeding for improving drought tolerance in chickpea.

Heat tolerance

Chickpea being a cool season food legume suffers heavy yield losses when exposed to heat stress at reproductive (flowering and podding) stage. The optimal temperatures for chickpea growth range between 10 C and 30 C. Reproductive phase (flowering and seed development) of chickpea is particularly sensitive to heat stress. A few days of exposure to high temperatures (≥ 35 C) during reproductive phase can cause heavy yield losses through flower and pod abortion. Recent studies indicate that the high temperatures reduced pod set in chickpea by reducing pollen viability and pollen production per flower (1, 2).

A simple and effective field screening technique for reproductive stage heat tolerance in chickpea has been developed at ICRISAT, Patancheru in southern India. Patancheru (latitude 17° 36' 10" N, longitude 78° 20' 39" E), is an ideal location for screening chickpea for heat tolerance because it has a warm and short growing season (90-100 days) for chickpea. Long-term weather data was used to decide the sowing time that would coincide the reproductive phase of the crop with high temperatures (> 35 C). At Patancheru, chickpea is normally sown in the month of October and harvested in January/February. It was found that if chickpea is sown in the month of February, the highest temperatures would be generally above 35 C starting from the initiation of flowering to crop maturity. Though the October-sown crop can be grown on residual moisture without any supplementary irrigation, the February-sown crop has to be irrigated frequently (at 10-15 days interval). It was found that number of filled pods per plant in late-sown crop can be considered as a selection criterion for reproductive stage heat tolerance.

The recent studies on screening of chickpea genotypes for heat tolerance indicate existence of large genotypic variation for reproductive stage heat tolerance in chickpea. Several heat tolerant genotypes have been identified which include landraces (e.g. ICC 1205, ICC 1356, ICC 4958, ICC 6279, ICC 15614), breeding lines (e.g. ICCV 07104, ICCV 07105, ICCV 07108, ICCV 07109, ICCV 07110, ICCV 07115, ICCV 07117, ICCV 07118, ICCV 98902) and cultivars (e.g. JG 14, JG 16, JG 130, JAKI 9218, JGK 2, KAK 2).

Figure 2. A heat sensitive (left) and a heat tolerant (right) line of chickpea grown under heat stress conditions at ICRISAT, Patancheru

The availability of effective, efficient and simple field screening technique for heat tolerance greatly facilitate chickpea breeding for heat tolerance. The general breeding scheme includes growing of segregating populations (F_4 or F_5) under late sown conditions for selecting heat tolerant plants based on the number of filled pods per plant. Then, single plant progenies are developed from the selected heat tolerant plants and evaluated further for grain yield and other desired traits (resistance to key diseases, seed traits, etc) under normal and heat stress conditions.

A heat tolerant breeding line ICCV 92944 has been released for cultivation in Myanmar (as Yezin 6) and India (as JG 14) and becoming popular for sowing under late-sown conditions (e.g. rice fallows). In addition, several other popular cultivars (JG 16, JG 130, JAKI 9218, JGK 2, KAK 2) were found to be heat tolerant.

Marker-assisted selection for heat tolerance can further accelerate breeding process and facilitate combining different desired traits. Recombinant inbred lines (RILs) have been developed from crosses between highly tolerant and highly sensitive lines for heat tolerance. These are being evaluated to identify molecular markers linked to heat tolerance genes. Efforts are also being made to identify candidate genes for heat tolerance. It is anticipated that several new heat tolerant cultivars of chickpea will be released in the coming years and provide greater choices to the farmers. ■

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