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Review

Scope for improvement of yield under drought through the root traits in chickpea (*Cicer arietinum* L.)

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ABSTRACT

Chickpea (*Cicer arietinum* L.) is a major grain legume crop in South Asia, and terminal drought severely constrains its productivity. In this review, we describe how root systems can improve the productivity of chickpea under the terminal drought that occurs in a receding stored soil water conditions in central and south India and propose possible breeding and screening methods. In chickpea, total root biomass in early growth stages has been shown to significantly contribute to seed yield under terminal drought in central and south India. Maximising acquisition of water stored in 15–30 cm soil layer by roots had greater implications as the timing of absorption, available soil water and root size matches well for the complete use of water from this zone. However, deeper root systems and a greater exploitation of subsoil water offers potential for further productivity improvements under terminal drought. As proof of this concept, contrasting chickpea accessions for important root traits, such as root biomass and rooting depth, have been screened in a chickpea germplasm collection which comprises rich diversity for root traits. Through analysing mapping populations derived from crosses between these accessions, a 'QTL hotspot' that explained a large part of the phenotypic variation for the major drought tolerance traits including root traits was identified and introgressed into a leading Indian chickpea cultivar. Yield advantages of the introgression lines were demonstrated in multi-location evaluations under terminal drought. As an alternative screening method, that would indirectly asses the root system strength, to identify further promising chickpea genotypes with multiple drought tolerance traits, the leaf canopy temperature and carbon isotope discrimination measurements can be proposed.

Contents

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1. Introduction

Chickpea (*Cicer arietinum* L.) is the third most important pulse crop worldwide (FAOSTAT, 2014), and South Asia alone contributes approximately 72% of this production. Chickpea cultivation areas have some major agro-ecological environments, such as (i) stored soil moisture systems in South Asia, (ii) in-season rainfall in Mediterranean, (iii) alkaline sands in North India (iv) alluvial soils in northwest India and Nepal and (v) lower water holding capacity soils in southern Australia (Saxena, 1984; Berger and Turner, 2007). In cultivation environment (i), chickpea is predominantly grown as a post-rainy season crop on conserved soil moisture and experiences progressive terminal drought stress with varying intensity. This terminal drought is a major abiotic constraint for the productivity of chickpea in central south India. In global chickpea production, the loss due to drought stress is severe and is estimated as 33%. However, approximately 19% of this loss was estimated to be recoverable through genetic improvement efforts (Subbarao et al., 1995; Varshney et al., 2009). Therefore, it becomes necessary to concentrate more on improving the productivity of chickpea under drought environments.

It is well recognised that breeding for better yield under drought conditions is difficult because of the spatial and temporal variability of available soil moisture across years and exhibited low genotypic variance in yield under those conditions (Ludlow and Muchow, 1990). Under such circumstances, genetic improvement by incorporation of traits that are known to contribute to yield under drought into well-adapted genotypes is suggested to be a viable alternative (Bidinger et al., 1982; Blum et al., 1983; Foulkes et al., 2001; Wasson et al., 2012). It is analytically hypothesized that yield stability can be improved by maximising any one of the following water-related yield components: (i) overall transpiration (T), (ii) transpiration efficiency (TE) and (iii) harvest index (HI) under moisture-limited environments (Passioura, 1977). Nevertheless, efficiency of water use depends more on optimised seasonal distribution of soil moisture use expressed as high water use efficiency for grain yield due to their relative moderate water use and high harvest index (Blum, 2009). Some key traits can be visualised to contribute to each of these components.

Two major root traits, root prolificacy and rooting depth, are well recognised to confer yield advantages in chickpea grown under constantly receding stored soil water conditions that typically occur under terminal drought stress in central and south Indian environments (Ludlow and Muchow, 1990; Saxena and Johansen, 1990; Turner et al., 2001). These root traits were shown to influence not only T via soil moisture utilisation but also HI under terminal drought environments (Kashiwagi et al., 2006; Zaman-Allah et al., 2011). Since the 1990s, efforts have been made, particularly at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) located in South Asian with predominantly a stored soil moisture environment and the International Center for Agricultural Research in the Dry Areas (ICARDA) in the Mediterranean with an in-season rainfall environment, to identify chickpea germplasm accessions that possess large root mass and deep rooting (Saxena et al., 1993; Singh et al., 1995). It was confirmed that yield stability should be possible by the incorporation of large root systems under terminal drought stress in South Asian stored soil moisture environments (ICRISAT). However, some concerns have also been raised, including needless biomass partitioning into roots (Passioura, 1983) and unnecessary energy loss, as the root system is known to respire more vigorously than the shoot system (Van der Werf et al., 1988; Krauss and Deacon, 1994). These arguments necessitate verification of the available data and reassessment of the need for improvement of root systems in chickpea.

This review, therefore, mainly focuses on root systems that have major impact on improving the agronomic performance of chickpea under terminal drought in central and south India, a major chickpea production area where major progress is seen in incorporating the root traits into chickpea drought breeding programs.

2. Current status of drought productivity improvements through the root system in chickpea

2.1. Characterisation of terminal drought environments in central south India

Drought characterisation, particularly in terms of available soil water depletion dynamics, is critical for developing a drought breeding strategy. In central and south India, the cropping season for chickpea is usually from October/November to February (post-rainy season). During this period, chickpea must rely on stored soil moisture during the winter because in-season rainfall is low and unpredictable (Summerfield et al., 1990). The maximum temperature during the crop growing post-rainy season on an average is 30.6 °C, fluctuating between 19.0 and 39.5 °C (ICRISAT weather station, 1990–2014). As an example, black cotton soils (Vertisols) cropped with chickpeas in post-rainy season, can store up to 250 mm of available water. Potential evapo-transpiration demand during the 4 month period extending from November to February is typically within the range of 300–350 mm for most chickpea growing areas in the region. Therefore, even if the soil profile is fully charged at the beginning of the crop season and with some rainfall during the reproductive period, the chickpea crop will still suffer from water deficit, and thus the seed yields seldom exceed 0.7 t ha^{-1} (Jodha and Subba Rao, 1987). Therefore, drought that constantly intensifies in severity with advancing growth, also called terminal drought, is typical of chickpea cultivated in the region and is the most serious abiotic constraint that limits seed yield the most.

2.2. From drought escape to drought avoidance

With the use of powerful soil water prediction models and geographic information systems (GIS) as the tools (Keig and McAlhine, 1974), it is possible to divide the chickpea growing area into various geographical zones. In central-south India where the terminal drought is early and severe, early or extra-early chickpea varieties have been developed for escaping very severe drought intensity at the end of cropping season. This characteristic could be derived from thermo-sensitive chickpea germplasm but not the photoperiodic response (Berger and Turner, 2007; Berger et al., 2011). The photoperiodic sensitivity is clearly a necessity to evade the twin stresses of low winter–spring temperatures and terminal drought in Mediterranean environments where the thermo-sensitivity alone would delay the flowering, and thus would ensure exposure to terminal drought. Applications of this drought escape strategy had brought success in terms of the yield stability in central south India. Chickpea production has become profitable, and the production area has increased in this region with the recent introduction of short-duration varieties such as ICCV 2, ICCC 37, ICCV 10 (Kumar and Rao, 2001) and KAK 2 (Gaur et al., 2006). However, the seed yield of early maturing chickpea cultivars are penalised as their total photosynthetic period gets limited. For this reason, in breeding