Efforts and strategies for alleviation of drought tolerance in chickpea in India

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Among the various cool season pulses grown in India, chickpea (*Cicer arietinum* L.) occupies an important position in rainfed agriculture. Chickpea is largely grown (>67% area) on conserved/residual moisture, contributing about 45% to the total pulses production in India. Being a rainfed crop, it often faces terminal drought stress. When chickpea sowing is delayed in fields vacated by paddy in the presence of terminal heat, soil moisture stress further limits its productivity. This necessitates the adoption of suitable strategies to alleviate *per se* drought tolerance in chickpea. Two main strategies, integrated breeding and transgenic technology, have been adopted for developing drought-tolerant varieties. The third potential strategy is utilization of nanotechnology, which has not been tried under Indian NARES. Systematic breeding efforts resulted in development of varieties having *per se* drought tolerance (RSG 44, Vijay, RSG 888, JG 74, Pusa 2024), and escape (JG 11, JG 16, JSC 56, IPC 2006-77 etc.) exploiting earliness. QTLs responsible for drought tolerance have been identified in chickpea genotype ICC 4958, which have been transferred, and drought-tolerant elite breeding lines have been developed. MAGIC and NAM populations combining drought and heat tolerance are now becoming available for identification of elite breeding lines having combined tolerance to both stresses for their possible release. Exploitation of transgenic technology using DREB gene has also shown promise. The use of nano-particles in enhancing root development and growth vigour in chickpea has opened the doors for exploitation of nanotechnology for alleviation of *per se* drought tolerance.

Transgenic and CRISPR Cas approaches to improving the grain yield of maize under drought stress conditions

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There is a significant challenge to meeting the crop productivity demands for feeding an increasing global population. Lack of sufficient water is a major limiting factor to crop production, and the development of drought-tolerant germplasm is desired. We have used multiple approaches to show that modifying ethylene biosynthesis or signaling can enhance drought tolerance of maize. Initially, we demonstrated that reducing the expression of *ACS6* (a gene that encodes an ethylene biosynthetic protein) by approximately 50% can increase grain yield under field drought stress conditions. Subsequently, we discovered a family of novel negative regulators of ethylene signal transduction in *Arabidopsis* and maize. These regulators are encoded by the *ARGOS* gene family, and in transgenic plants over-expression of ARGOS genes reduces ethylene sensitivity. Field testing showed that ARGOS8 maize transgenic events had a greater grain yield relative to controls under both drought-stress and well-watered conditions.We then employed a CRISPR-Cas-enabled advanced breeding technology to generate novel variants of ARGOS8. The native maize GOS2 promoter, which confers a moderate level of constitutive expression, was inserted into the 5'-untranslated region of the native ARGOS8 gene or was used to replace the native promoter of ARGOS8. A field study showed that relative to the comparator, the ARGOS8 variants increased grain yield by five bushels per acre under flowering-stress conditions and had no yield loss under well-watered conditions. We believe that continued advancement in our understanding of the key biological processes in maize will enable significant improvements in crop productivity.