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*Review*

# Impact of High Temperature and Drought Stresses on Chickpea Production

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**Abstract:** Global climate change has caused severe crop yield losses worldwide and is endangering food security in the future. The impact of climate change on food production is high in Australia and globally. Climate change is projected to have a negative impact on crop production. Chickpea is a cool season legume crop mostly grown on residual soil moisture. High temperature and terminal drought are common in different regions of chickpea production with varying intensities and frequencies. Therefore, stable chickpea production will depend on the release of new cultivars with improved adaptation to major events such as drought and high temperature. Recent progress in chickpea breeding has increased the efficiency of assessing genetic diversity in germplasm collections. This review provides an overview of the integration of new approaches and tools into breeding programs and their impact on the development of stress tolerance in chickpea.

**Keywords:** chickpea; climate change; drought; high temperature; yield

## 1. Introduction

Chickpea is a cool season crop and an important source of protein. Chickpea is grown worldwide in over 54 countries in 12.7 Mha with annual production of 12 Mt. Its annual production has fluctuated over the last five years (2012–2016) due to climate change [1]. Climate change has become a major challenge in chickpea production and productivity. Negative impacts of climate change are likely to result from the effects of drought, high temperature, low temperature, and excessive moisture and these factors affect crop yields in many regions globally. Food production has been affected by climate change in central and south America, Africa and Australia [2]. Changes in climate events and extreme weather have been observed recently. The frequency of heat waves has increased in different parts of Europe, Australia and Asia. Climate-related extremes such as heat waves, droughts and floods have limited crop yields [2]. Global mean surface temperature for the mid and late 21st century is projected to rise by 2 °C which will lead to an extreme variation in precipitation events, more heat waves and fewer cold temperature extremes [3]. Such changes in climate will impact chickpea production and yield and result in grain yield decreases of up to 19% in chickpea [4]. The crop generally encounters terminal moisture and heat stresses in chickpea growing areas which lead to reduced grain yield [5]. Hence, this review will primarily address high temperature and drought stress and their impact on chickpea production. Furthermore, there is a need to develop climate resilient chickpea cultivars to sustain its production and productivity.

Drought and high temperature stresses are the most important constraints among climate events. It is estimated that 50% of yield losses are caused by drought and heat stresses [6]. Chickpea is largely grown as a rotation crop in the cereal cropping system on residual soil moisture. This often leads to moisture stress towards the end of the cropping season with frequent episodes of heat stress. Thus, the crop is exposed to stress conditions during the reproductive stage causing yield losses. Yield loss was estimated to be 10%–15% for every 1 °C above the optimum temperature [7]. A decrease in chickpea yields of 53 kg/ha was observed with a 1 °C increase in seasonal temperature [8]. Similarly, with every 0.1 °C temperature rise combined with 31% reduction in seasonal rainfall, the yield of chickpea decreased by 38.5 kg/ha [9]. This shows that high temperature and drought are the major factors that affect chickpea production.

Significant progress in the improvement of chickpea adaptation to drought and heat stress has been made in recent years. Plant responses to stress environments have been studied in the field and controlled environments. Screening techniques have been developed by studying plant physiological responses and male reproductive organs in chickpea [10,11]. In this review, we discuss breeding approaches for improving yield under stressed environments. We also report, how knowledge of phenological and physiological mechanisms can contribute to achieving these aims. In addition, recent developments in breeding, genetics, genomics and agronomic strategies to improve stress tolerance in chickpea are also discussed.

## 2. Effect of Drought on Chickpea

Drought is responsible for 40%–45% of chickpea yield losses across the globe [12]. Drought tolerance breeding research work on chickpea has been conducted for over two decades. Previous research has documented drought responses to different traits such as early maturity (drought escape), root traits (drought avoidance), carbon isotope discrimination, rate of partitioning, shoot biomass and grain yield [13–17]. The physiological and biochemical changes under drought are well documented in earlier reports and summarised in Table 1. These changes in plants showed how plant growth and development are affected by drought. The adverse effects of drought can be reduced by developing resilient chickpea cultivars with improved drought tolerance using various genetic approaches. The primary goal in developing resilient cultivars is to identify genotypes using simple screening methods. This review also explains the existing genotypes for drought tolerance which can be used in different environments. International Crops Research Institute for Semi-arid Tropics (ICRISAT) identified ICC 4958 as a short duration drought tolerant genotype which has larger root length and volume [18]. This genotype has been used as a donor parent and a reference genotype in drought research. However, differences in crop duration and yield potential are known to influence grain yield under stress [19]. Higher yields are more common in short duration than long duration genotypes under stress. To eliminate the differences in crop phenology and stress escape, the multiple regression approach was used by Bidinger [20]. This approach has considered grain yield under drought to be a function of yield potential and time to 50% flowering [14]. Based on this method, five of the most drought tolerant genotypes and 20 highly drought sensitive genotypes among 211 genotypes were identified [14]. The result also classified ICC 4958 as a moderate drought tolerant genotype. Recent advances in phenotyping platforms such as non-destructive imaging techniques are now available worldwide for field and growth chambers phenotyping. Various phenotyping portable devices are also available to measure photosynthesis (LiCOR 6800, LiCOR Biosciences, Lincoln, NE, USA), chlorophyll (chlorophyll meter, e.g., SPAD meter, Konica Minolta Inc., Osaka, Japan), light (spectrometer), leaf canopy temperature (infrared thermometer), leaf transpiration (leaf porometer), and leaf area (leaf area meter). An outdoor pot experiment of eight chickpea genotypes was conducted in ICRISAT to measure canopy temperature using infrared thermometer under terminal drought condition [21]. The results revealed that a large number of genotypes is needed to detect differences. Under field conditions, canopy temperature depression (CTD) was calculated to estimate crop yield under drought in ICRISAT. CTD recorded at mid reproductive stage (62 days after sowing) was positively associated with grain yield [22]. Therefore, drought tolerance breeding needs the understanding of crop developmental stage and intensity and duration of stress because plants can continue growing with a limited water supply.

**Table 1.** Mechanism of phenology, physiological and biochemical changes in drought and heat tolerance in chickpea.

| Stress | Phenology, Physiological, Biochemical Changes and Stress Tolerance Index | References |
|---|---|---|
| Drought | Root length density | [12] |
| | Chlorophyll loss, low water potential | [23] |
| | Shoot biomass and grain yield | [13] |
| | Drought tolerance index | [13] |
| | Early flowering | [24] |
| | Carbon ($\Delta^{13}C$) isotope discrimination during the photosynthetic activity | [25] |
| | High osmatic adjustment with low water potential to maintain turgor | [26] |
| | High water-soluble carbohydrate content in stressed plants | [27] |
| | Higher catalase activity under drought which inhibits the osmatic stress | [27] |
| | Small leaf area with less water loss by transpiration | [19,28] |
| | Reduced pollen viability, pistil function and pod set | [29] |
| | Canopy temperature depression during mid-reproductive stage | [22] |
| Heat | Pod number per plant, harvest index | [30] |
| | Heat tolerance index | [30] |
| | Grain yield | [7] |
| | Application of abscisic acid (ABA) induces heat tolerance | [31] |
| | Reduced pollen viability | [11,31] |
| | Failure of fertilization due to oxidative stress | [31] |
| | Early flowering, filled pod number per plant | [32] |
| | Canopy temperature depression during reproductive stage | [32] |
| | Reduced enzyme activity (Rubisco, sucrose phosphate synthase, sucrose synthesising enzyme) due to stress | [33] |
| | Reduced pollen function due to lower sucrose level in pollen | [33] |

## 3. Effect of Heat Stress on Chickpea

Hot (>30 °C) and dry atmospheric conditions lead to profligate loss of flower buds and open flowers in chickpea [34]. High temperatures (≥35 °C) during reproductive development reduced grain yield [32]. Temperatures ≥35 °C produced yield losses of up to 39% [35]. Heat stress during reproductive development is a major cause of yield loss due to pollen sterility. Temperatures ≥35 °C affected male reproductive tissues (pollen and anther) function and pod set. Both anther and pollen showed structural abnormalities such as changes in anther locule number, anther epidermis wall thickening and pollen sterility [31]. Both pollen fertility and stigma function can be affected at 45/35 °C due to oxidative stress in the leaves which led to poor yield [36]. A summary of physiological and biochemical changes under heat stress is outlined in Table 1. However, substantial variation among genotypes were found under high temperature. Genotypes varied their sensitivity to heat stress, and yield loss varied from 10%–15% for every degree increase in temperature above the optimum temperature [7]. Generally, temperature stress reduces grain filling rate and ultimately seed weight [37]. Sucrose and starch concentrations decreased in chickpea seeds under heat stress during the grain filling period [25]. Devasirvatham et al. [35] observed large genetic variation among 167 genotypes under heat stress. The phenological trait (days to first flowering) and grain yield under heat stress was negatively associated in long duration compared with medium to short duration genotypes. Short duration genotypes had yield advantage due to heat escape. Chickpea genotypes were classified based on their response to heat stress using heat stress index and 10 stable heat tolerant genotypes and 11 stable sensitive genotypes were identified among 167 genotypes. Canopy temperature was measured and canopy temperature depression (CTD) was calculated. Genotype with lower CTD (1–3 °C) had lower grain yield than those with higher CTD (>4 °C) [35]. Mapping populations are being developed at ICRISAT and the University of Sydney from the genetic material identified from this research. Compared with drought research in chickpea, the findings related to heat stress are limited. Heat stress during the reproductive period affects grain yield due to poor pollen viability and reduced pod set.

## 4. Adaptation Mechanisms of Chickpea Plants to Extreme Events of Climate Change

### *4.1. Drought Escape and Avoidance*

Plants can escape terminal drought through early phenology (short duration). This has been a successful breeding strategy in chickpea under drought [38]. Days to first flowering (DFF) i.e., the number of days taken from sowing to first flowering is a key phenological trait. A range of 25–30 days to first flowering is classified as short duration by ICRISAT. This adaptation mechanism has shown enhanced yield in chickpea growing areas in south India [38] and Myanmar [39]. Several early maturing desi and kabuli types were developed for short growing season. Early varieties such as KAK 2 (kabuli) and JG 11 (desi) have provided stable chickpea productivity in south India [38]. Early maturing kabuli genotypes such as ILC1799, ILC3832, FLIP98-141, ILC3182, FLIP98-142C, ILC3101 and ILC588 under dry land conditions of Iran were identified as early maturing genotypes [24]. Therefore, early flowering and maturity escapes drought and avoids yield losses. However, the early maturity genotypes with a short grain filling period did not show any substantial yield increase. A shorter vegetative period combined with a longer grain filling period produced higher grain yield [40].

Chickpea roots can use water from 15–30 cm soil layer [13]. Total root biomass in the early growth stage i.e., end of the vegetative period and seed yield under terminal drought showed a positive correlation. However, deeper root systems and use of subsoil water above 30 cm offers possible yield increase under terminal drought. Root biomass and rooting depth are identified as drought tolerance traits responsible for terminal drought tolerance [41]. Drought tolerant (ICC 4958) and sensitive (Annegiri) genotypes were identified by ICRISAT researchers and a recombinant inbred line (RIL) population was also developed by [15]. Furthermore, Kashiwagi studied the genetic effects of root and shoot from two different crosses (ICC283 x ICC82361) and (ICC4958 x ICC1882). The study suggested that additive gene action controlled root length density and root dry weight [41]. However, the critical component of drought tolerance was also related to a conservative pattern of water use under terminal drought [21]. Furthermore, soil water exploitation at the reproductive stage must match crop phenology such as 50% flowering and pod development in order to utilize root traits to achieve drought avoidance in chickpea.

### *4.2. Heat Escape and Avoidance*

With the current understanding of available resources, ICCV92944 (JG14) was identified as a heat tolerant genotype which escapes heat stress through early maturity. It is a promising variety under late sown conditions of cereal based cropping system in India [42]. Therefore, early flowering with long reproductive period is an important trait for heat and drought escape mechanism. To avoid the escape and avoidance mechanisms, a heat tolerance index was used to identify stable heat tolerant and sensitive genotypes by [30,35]. New tolerant and sensitive genotypes were identified and made available for the breeding program. ICRISAT developed a set of 296 $F_{8–9}$ recombinant inbred lines (RILs) of the desi cross ICC4567 x ICC15614 to study genetic variability and traits response to high temperature under field conditions. The most affected trait was %pod set. Genotype by environment interactions were also studied in the RILs population to understand the response of physiological traits to environments [43]. For chickpea yield potential to meet future demand, understanding the physiological causes of G x E for genetic improvement would be valuable to improve crop adaptation. In addition, from the RILs population, quantitative trait linkages (QTLs) associated with specific traits of heat responses have been identified [44]. Although the development of molecular markers and genome sequencing is available in chickpea, a better understanding is needed of the genomic region associated with individual QTLs for heat and drought which contain a few hundred genes [45].

## 5. Strategies to Improve Breeding for Tolerance to Extreme Events of Climate

Breeding for drought and heat tolerance plays an important role to study genetic diversity for selected traits which contribute to yield. Many diverse genotypes are now available for drought and heat tolerance breeding programmes [7,13,20,30,32,35]. Segregating populations from A1 x ICC4958; ICCV2 x ICC4958 were evaluated for physiological traits (grain yield, root biomass) contributing drought tolerance [46]. Recently, an effort was made to understand drought tolerance in chickpea through genomics assisted breeding [47]. High density genetic maps have been developed using different markers (Simple Sequence Repeats (SSR), Single Nucleotide Polymorphism (SNP) and Diversity Arrays Technology (DArT)). Main effect quantitative trait loci (QTLs) and epistatic QTLs for different drought tolerance traits in two mapping populations (ICC4958 x ICC1882; ICC283 x ICC8261) revealed a genomic region referred as 'QTL-hotspot' which controls 12 drought tolerance traits such as root length density, root surface area, shoot dry weight, plant height, days to 50% flowering, days to maturity, harvest index, 100 seed weight, biomass, yield, pods per plant, and seeds per pod [45]. This region is considered as a candidate genomic region for drought tolerance. Similarly, four QTLs for number of filled pods, total seeds, grain yield and %pod set were found under heat stress using RILs developed from the desi chickpea cross ICC4567 x ICC15614 [44]. Furthermore, multiparent advanced generation inter-cross populations (MAGIC) were developed by ICRISAT using a set of eight well adapted drought tolerant lines such as ICC4958, ICCV10, JAKI9218, JG11, JG130, JG16, ICCV97105 and ICCV00108. This approach provides gene discovery and understanding of complex traits responsible for drought [47]. These genetic approaches will be used for managing terminal drought and heat stresses in the future. There is a global effort to identify short duration chickpea varieties for drought and heat stresses with high yield potential under semiarid conditions [48]. The Plant Breeding Institute—The University of Sydney has developed mapping population for kabuli and desi chickpeas to understand the traits contributing to heat tolerance [49]. These efforts will lead to marker-assisted selection (MAS) which is under development in pulses. To achieve MAS, the chickpea breeders need to develop trait-specific mapping populations and map the QTLs [50]. It will facilitate the next steps to develop elite chickpea cultivars for drought and heat tolerance.

## 6. Conclusions and Strategic Approaches to Develop Resilient Cultivars

Global climate change is expected to increase the occurrence and severity of drought and heat waves. Food security in the future will depend on the development of cultivars with improved adaptation to drought, heat stress and yield stability. Therefore, it is important to improve the efficiency of breeding, to increase productivity and to reduce the gap between yield potential and yield in the grower's field. This detailed review explains the progress on chickpea breeding under drought and high temperature. This review also outlines the strategic approaches (Figure 1) to develop resilient cultivars which include:

- Development of simple screening methods to identify drought and heat tolerance chickpea genotypes to the selected environments.
- Determination of physiological and biochemical responses of genotypes to stress and underlying genetic basis of these traits.
- Identification of molecular markers linked to major QTLs that elucidate variation in drought and heat tolerance.

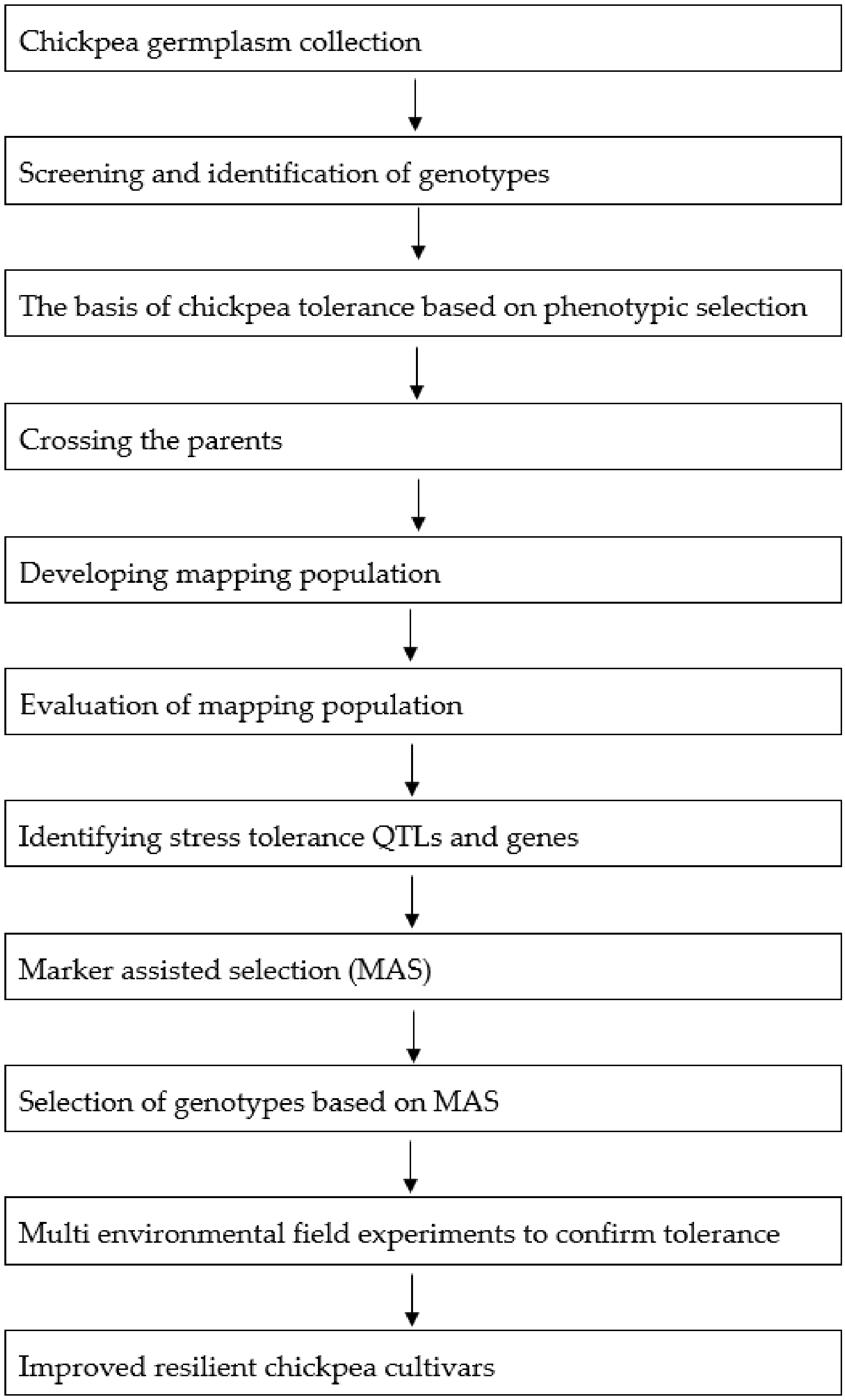


**Figure 1.** The strategic approaches to developing resilient cultivar.

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