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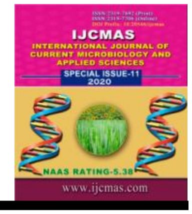

Original Research Article

Temperature Stress in Chickpea and its Improvement Strategies

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A B S T R A C T

Chickpea is the third major cool season grain legume crop in the world after dry bean and field pea. Chickpea faces various abiotic stresses during its life cycle such as drought, cold, terminal heat and salinity. Cold temperature stress represents a major limiting factor in chickpea production. The reproductive stage represents the most vulnerable phase within where plenty of damaging events may take place, such as, the juvenile buds drop, aborted pods, reduced pollen viability and stigma receptivity, inhibited pollen tube growth and ultimately, deteriorated seed quality and seed yield. So also the rise in temperature beyond certain optimum level is detrimental to the crop growth causing severe injuries that are collectively termed as 'heat stress'. Being a cool season crop, chickpea also susceptible to high temperature (30–35°) for few days at flowering stage and can cause substantial yield loss. Both high and low temperature stresses cause grain yield loss. Recent chickpea breeding programmes targeting both high and low temperature stresses have been initiated by many countries including India, with global centres such as ICARDA and ICRISAT supporting the wider effort through the characterization and exploitation of genetic resources. Screening for tolerance to temperature stresses has identified many promising sources of tolerance to both high and low temperature in chickpea. This review provides a comprehensive account of the current information regarding the effects of high and low temperature stress to chickpea. Future research directed toward understanding the mechanisms involved in cold and heat tolerance of chickpea is also suggested.

Keywords

Heat stress, Cold temperatures, Chickpea, Yield loss

Introduction

Chickpea (*Cicer arietinum* L.) is an important pulse legume cultivated and consumed across the world. India is the largest producer and consumer of chickpea in the world. It is the major pulse crops of the subcontinent grown on an area of about 9.54 mha with a production of 9.08 mt and productivity of 951 kg ha-1 (Agricultural Statistics at a Glance, 2016). Chickpea is an important legume in many farming systems and provides biological N fixation which benefits the entire farming system. However, chickpea production is hampered by biotic and abiotic constraints depending on the ecological region. Among abiotic stresses, drought, heat and cold stresses are the most important yield limiting factors (Gunes *et al.,* 2008; Boyer, 1982); accounting for up to 50% of chickpea production losses for drought, and 15–20% of yield losses for low and high temperatures (Varshney *et al.,* 2013). This situation is exacerbated by climate change which may cause higher intensity and frequency of droughts, heat waves and cold spills in the arid and semi-arid areas (IPCC, 2007) where chickpea is traditionally cultivated.

Adverse effect of heat stress on grain legumes is increasing due to global warming. Chickpea mostly grown in semi-arid regions frequently encounters of heat waves that affects crop growth and yield (Jumrani and Bhatia, 2014). High temperatures stress in chickpea production is mainly associated with climate change and changes in cropping systems that have shifting chickpea production from cooler region to warmer region (e.g. India) (Gowda *et al.,* 2009; Anwar *et al.,* 2007). Both situations, the crop is experiencing high temperature during reproductive stage. Therefore, the effects of heat stress on chickpea growth, development and yield are important to understand by observing agronomic, physiological and biochemical traits to develop high temperature tolerant cultivars

Chickpea experiences low temperature (0–12°C) in north India as a spring crop. It is grown in Western Asia and North Africa and Europe as a winter crop which experiences freezing temperature (down to −10°C) (Toker *et al.,* 20017; Kanouni *et al.,*; 2015). Low temperature has negative impact on yield and 15–20% of yield loss was estimated (Chaturvedi *et al.,* 2009). In most agricultural species, suboptimal temperatures can be divided into chilling range and freezing range. The freezing range temperatures for chickpea as below –1.5°C, which is the typical freezing point of plant tissue (Graham and Patterson, 1982), and chilling range temperatures for chickpea as between –1.5°C and 15°C. Temperatures up to 15°C have been demonstrated to cause flower and pod abortion in parts of the Indian subcontinent (Srinivasan *et al.,* 1998; Clarke, 2001). The freezing stress predominantly occurs during the seedling and early vegetative stages of crop growth. Sometimes frost are also a problem when they occur in the late vegetative and reproductive phenological stages. On the other hand, temperatures within the chilling range can limit the growth and vigour of chickpea at all phenological stages, but are considered most damaging to yield at the reproductive stages.

Impact of low Temperatures

A prolonged period of low range temperatures at any phenological stage of development in chickpea has detrimental effects on final seed yield. During germination, chilling range temperatures result in poor crop establishment, increased susceptibility to soil-borne pathogens, and reduced seedling vigour. At the seedling stage, long periods of chilling range temperatures can retard the growth of the plant and, in severe cases, cause plant death. At the vegetative stage, low temperatures have a pronounced negative effect on plant growth and dry matter production. Less dry matter production reduces the reproductive sink that the plant can support, which, in turn, reduces potential yield. Flower, pod, or seed abortion are further symptoms.

Chickpea yields are usually limited low range temperatures during flowering, causing extensive flower and pod abortion (Siddique and Sedgley, 1986). The high yield potential of early sown crops (high biomass) or early flowering genotypes is largely limited by abortion of flowers and pods in late winter and early spring, which in turn leads to low harvest index. Although delayed sowing can reduce flower and pod abortion associated with low temperatures, seed yield is often limited by terminal soil moistures, a common feature in this environment (Turner *et al*., 2001). Early flowering would benefit yield if flowers were fertile, because pod development and seed filling can start earlier and so avoid terminal soil moisture stress (Leport *et al.*, 1999). Greater tolerance to low temperatures at flowering therefore is required in chickpea in order to take advantage of the full benefit of early flowering and high yield potential associated with early sowing in short season. Prevalence of low range temperatures during early flowering lead to excessive floral abortion which is a major cause of low pod and seed set in chickpea (Saxena, 1980; Srinivasan *et al.*, 1998, 1999). Although such loss is considered an adaptive mechanism that stimulates vegetative growth and provides additional nodes for production of flowers and pods (Saxena, 1984), this in only true in environments that are not limited by soil moisture toward the end of the growing season.

Low Temperature Stress at Different Stages

Developmental Stage

The germination of chickpea, starts the growth process of a quiescent or dormant embryo, and is evidenced by the growth of the embryonic axis (de Rueda *et al.*, 1994). In chickpea, 0^0C has been proposed to be the base temperature for germination (Singh and Dahliwal, 1972; Siddique *et al.*, 1983; Ellis *et al.*, 1986; Calcagno and Gallo, 1993). Thus, in freezing soils, chickpea will not germinate.

Seedling Stage to Early Vegetative Stage

Plants at the autotrophic stage are more vulnerable to temperature stress than those at the heterotrophic stage prior to germination because their endosperm resources have been exhausted. The degree of vulnerability varies with the age of the plant and in chickpea, tolerance to freezing range temperatures has been shown to decrease at the plant progresses from the seedling stage (most tolerant) to flowering (least tolerant) (Wery 1990; Singh *et al.*, 1995). The main effects of low temperatures on the developing seedling are related to membrane injury and include reduced respiration and photosynthesis and loss of turgor, resulting in wilting and temperature-induced drought stress. The effect of early winter sowing is that chickpea plants in the early vegetative stage encounter gradually decreasing temperatures and photoperiods. During the winter season, night temperatures fall below zero and remain low for a long period. Although some studies report lines that withstand temperatures of –12°C in the post emergence vegetative stage, the minimum temperature at which chickpea generally seem to survive is –8°C (Wery, 1990). Yield increases exhibited by winter sown chickpea have been ascribed to the longer vegetative growth periods leading to a larger vegetative structure. This larger vegetative structure intercepts photosynthetically active radiation (PAR) more effectively in spring and supports a proportionally larger reproductive sink with adequate partitioning of dry matter (Singh *et al.,* 1997).Better utilization of PAR increases total biomass of winter sown chickpea, while retaining a similar harvest index (HI) to that of spring sown chickpea (Keatinge and Cooper, 1983; Siddique and Sedgley, 1986; Singh *et al.*, 1997).

Late Vegetative Stage

There is a high sensitivity to freezing damage at the more advanced vegetative stage (Calcagno and Gallo, 1993; Singh *et al.*, 1993; Singh *et al.*, 1995). Wery (1990) has suggested that the increased sensitivity to freezing range temperatures is due to the plant being unable to set osmoregulation mechanisms in motion during the active growth phase of the plant.

In chickpea, stem elongation during the vegetative stage means that the shoots are in air strata colder than that nearer to the soil surface. In chickpea, the duration of the vegetative phase of growth in either short or long photoperiods is negatively related to the mean diurnal temperature, irrespective of the genotype (Roberts *et al.*, 1985).

Freezing temperatures at this point in the crop's phenological development therefore can cause considerable damage and yield losses.

Reproductive Stage: Anthesis, Pollination, and Pod Set

The onset and duration of flowering in chickpea are functions of genotype, photoperiod, and temperature (Roberts *et al.*, 1985). Flowering is indeterminate and can extend for up to 60 days with leaf initiation and stem elongation continuing into the reproductive period (Knights, 1991). During the reproductive stage chickpea is far more likely to encounter temperatures within the illing range as opposed to temperatures within the freezing range.

Singh *et al.*, (1993) observed that plants at the reproductive stage do not tolerate freezing temperatures, such as those encountered chickpea is longer than spring sown chickpea, contributing to higher seed yield. Better utilization of PAR increases total biomass of winter sown chickpea, while retaining a similar harvest index (HI) to that of spring sown chickpea (Keatinge and Cooper, 1983; Siddique and Sedgley, 1986; Singh *et al.*, 1997).

Heat stress

Agronomic traits and their relationship with grain yield

Generally, temperature (>30°C) limited yield in cool season legumes such as chickpea, lentil, faba bean and field peas (Krishnamurthy *et al.*, 2011; Bhandari *et al.*, 2017;Bishop *et al.*, 2016; Jiang *et al.*, 2015). Plant growth, phenology, biomass accumulation and yield are important agronomic traits which depends on the crop ability to withstand or acclimate under abiotic stress (Prasad *et al.*, 2008). Phenological traits such as days to first flowering, days to 50% flowering and days to crop maturity plays a major role under high temperature. Under stress plants forced to maturity i.e. escaping from heat. Therefore, earliness can be observed through phenological traits. Significant variation in phenology in chickpea under heat stress was observed. Particularly, days to 50% flowering was delayed and days to crop maturity was hastened due to requirement of thermal time (growing degree days °C) to attain any developmental stage (Krishnamurthy *et al.*, 2011). Furthermore, grain yield under heat stress was negatively associated with phenology. To eliminate heat escape, classification of genotypes based on maturity (short, medium and long duration) and stress tolerance index would helpful to identify the genotypes that could be used for future breeding (Krishnamurthy *et al.*, 2011; Devasirvatham *et al.*, 2015]. Plant height, plant width, biomass accumulation, pod number, filled pod number, seed number per plant and grain yield are also plays significant role under high temperature. Plant height and width was affected under heat stress as well as biomass accumulation, pod number and seed weight (Krishnamurthy *et al.*, 2011, Upadhyaya *et al.*, 2013). Generally, high temperature reduces the duration of plant developmental stages and carbon assimilation process within the plant, resulting low biomass production and reduces source-sink activity (yield) (Harding *et al.,* 1990). The most affected yield traits in chickpea are pod number per plant and harvest index. Similar findings have been found in lentil (Kumar *et al.,* 2016)

Physiological traits and their relationship with grain yield

Generally, high temperature can negatively affect photosynthesis. The sensitive chickpea genotype at 40/30°C reduced chlorophyll content with a symptom of chlorosis leaves. The symptom of chlorosis in heat stressed plants is common and it was evident in mung bean (Kumar *et al.,* 2011). Due to inhibition of chlorophyll synthesis, the chlorophyll content may be affected under stress. However, the tolerant chickpea genotype maintained greater chlorophyll content and photochemical efficiency than sensitive genotypes (Kumar *et al.,* 2011). which correlated with yield reduction in sensitive genotypes (Kaushal *et al.,* 2013). High temperature affects membrane structure and function. Stress injury can be regulated by loss of membrane integrity and leakage of ions from cells (Salvucci and Crafts, 2004). Therefore, monitoring the function of membrane through electrolyte leakage has been used to screen thermostability under high temperature. The effects of heat stress on the function of membrane has been studied in legumes. Cell membrane thermostability and its correlation with sensitivity was observed (Srinivasan *et al.,* 1996) and chickpea is the most sensitive crop to high temperature. Similarly, membrane thermostability had linked with sensitivity in chickpea, lentil and faba bean (Ibrahim, 2011). Furthermore, Awasthi *et al.,* 2014 suggested that drought or heat and combined stresses decreased cellular oxidising ability, stomatal conductance, PSII function and leaf chlorophyll content in chickpea. Transpiration is the main reason of changes in leaf temperature due to abiotic stresses [Ibrahim, 2011; Blum, 1988). Canopy temperature can be sustained through transpiration by open stomata and maintained cool canopy. In addition to that, canopy temperature depression (CTD) is an indicator of the difference between plant canopy and air temperature. Since the plant closes stomata for certain period due to stress, this will change canopy temperature (Kashiwagi *et al.,* 2008)

Biochemical traits and their relationship with grain yield

Biochemical responses in plants is observed in the reproductive stage i.e. final stage of grain legumes which involves synthesis of carbohydrates, proteins and lipids in seeds (Weschke *et al.,* 2000). A positive correlation was found between seed dry weight and sucrose synthase activity under water stress in chickpea (Turner *et al.,* 2009). In chickpea, starch metabolism in the leaves affects sucrose availability in the developing seeds and the activities of enzymes related to these metabolic pathways were assessed (Awasthi *et al.,* 2014)Starch concentration, the starch synthesising enzyme were increased under heat-stressed chickpea plants than non-stressed plants. In the seed, the activity of enzyme was inhibited under heat stress. Sucrose in leaves and seeds, sucrose synthase in leaves and seeds and starch phosphorylase in seeds had strong correlation with seed weight per plant and biomass production under heat stress (Awasthi *et al.,* 2014)

Pollen as a trait and its relationship with pod set

In legumes, reproductive stage is known to be more sensitive to high temperature than vegetative stage. In reproductive stage, pre-anthesis, anthesis and post-anthesis are important developmental stages which are considered to be sensitive stages among flowering. Heat stress affects reproductive development in chickpea (Devasirvatham *et al.,* 2012)

Male (anther, pollen) and female organs (stigma-style, ovary) of flowers are severally affected by heat stress (≥30°C) associated with abscission of flower buds, flowers and pods, leading to significant yield loss [Nakano *et al.,* 2012, Duthion *et al.*,1991]. Recent findings in legumes revealed that pollen grains of chickpea (35/20°C) are more susceptible to high temperature (Devasirvatham *et al.,* 2012). Pollen sterility depends on tapetum (anther tissue) and pollen mother cell for pollen formation (Zinn *et al.,* 2010). Under heat stress, pollen grain fertility is also associated with sucrose content in leaves and anthers (Kaushal *et al.,* 2013, Kumar *et al.,* 2013). Under stress, pollen tube growth rate also plays an important role (Hedhly *et al.,* 2009). Pollen sterility due to heat stress in chickpea affects pod set and yield (Devasirvatham *et al.,* 2013) Therefore, analysis of pollen viability and pod set under high temperature is a trait for the study of high temperature tolerance in chickpea.

Adaptation Mechanisms of Chickpea Plants to temperature stress

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 (Gaur *et al.,* 2010). 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 [Krishnamurthy *et al.,* 2011, Devasirvatham *et al.,* 2015]. New tolerant and sensitive genotypes were identified and made available for the breeding program. ICRISAT developed a set of 296 F8–9 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 (Paul *et al.,* a, 2018). 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 (Paul *et al.,* b, 2018. 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 (Varshney *et al.,* 2014)

Both high and low temperature stresses cause grain yield loss. Cold stress encourages a prolonged vegetative period while high temperatures reduce the duration of the vegetative period. Reduced pollen viability and pollen germination on the stigma are the primary causes of poor pod set in chickpea following low temperature stress. Similarly, high temperature stress disrupts pollen viability and anther dehiscence. However, stigma receptivity is not affected by either stress. The rate and duration of seed filling are both decreased by cold and high temperature stresses.. Although screening for tolerance to high and low-temperature stresses has identified many promising sources of tolerance in chickpea, but still, there has been little attempt to extrapolate these findings across the world's core chickpea production areas. Overall, the heat and cold stress can be studied using an integrated approach that integrates genetic and physiological characterization of plant response to achieve plant breeding targets.

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