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Physiological, biochemical and molecular basis of thermo tolerance in chickpea (*Cicer arietinum* L.)

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Abstract
High temperature stress causes irreversible damage to the plant system. The optimum temperature required for different plants vary for the cardinal points as it is associated with the exposure time, age of the plant, growing conditions, previous history and other externalities. Heat stress during podding and seed filling stage is a major constraint in chickpea of cooler regions. The negative effects of high temperature stress can be overcome by designing crop genotypes with increased thermotolerance. The sensitive effect conferred by heat stress in plants results in negative mode of photosynthesis, nutrient and water use efficiency, membrane stability and assimilate proportioning. Chickpea plants occupy frequent biochemical changes for their growth and development during high temperature conditions. Triggering the constitutive expression of heat- specific proteins during stress situations has been identified to enhance thermotolerance in chickpea. This article highlights to review the key findings on heat stress responses of chickpea plants at physiological, biochemical and molecular levels.

Keywords: Chickpea, heat stress responses, physiology, biochemical reactions, molecular responses

1. Introduction

Tremendous emission of greenhouse gases from various sources is considered responsible for an exponential rise in the worlds' optimum temperature and ending in global warming. High temperature stress has become a major threat for agriculture worldwide because it markedly affects the overall growth, development and productivity of plants [1]. Knowing the mechanisms underlying the plant response to heat tolerance is important in major agricultural crops. During high temperature stress, plants activate a different metabolic pathways and processes which emphasize the need of physiological, biochemical and molecular research to bring out the mechanisms underlying high temperature response [2].

Chickpea (*Cicer arietinum* L.) is one of the important rabi crop faces various abiotic stresses. Among the stresses, high temperature stress poses major constraint in chickpea production during warmer climatic conditions. Potential yield of chickpea is greatly reduced during exposure to high temperature exceeding 35 °C [3]. High temperature has negative effect on overall growth and development of plants leading to potential losses in yield and production [4]. Heat stress causes direct and indirect effects at phenological, biochemical, cellular and molecular levels. Direct effects include protein modification, denaturation and aggregation and high discharge of membrane lipids. Indirect effects are failure of enzyme activity in mitochondria and chloroplast, reduction in photosynthetic ability, high respiration loss, membrane stability disturbance and reluctance of protein synthesis [5]. Increase of 1 °C in mean seasonal temperature causes yield loss up to 301 kg ha-1 in chickpea [6]. Therefore, in future food security rely on development of new varieties with ability to withstand high temperature conditions. Heat tolerance mechanisms vary among genotypes involving changes in morphological, physiological, biochemical and molecular functions [7], provides useful insights for programming strategies for enhancing crop performance. The incidence of important devasting chickpea diseases like Fusarium wilt also increases with the change of temperature inside and outside the soil. In an experiment conducted by Kapoor *et al.* [8] observed that microbial conidia and chlamydospores was dominant in upper (8-12 cm) soil surface and decrease in deeper soil. It clearly indicates that different layers of soil do affect the incidence of wilt in chickpea.

The extensive work on thermotolerance in chickpea is still lacking and need to be reviewed time to time, to make the scientific community aware of the latest findings to update them and also to give them guidance in deciding the directions of research they have been engaged on

Chickpea thermotolerance. In this small and crisp review, the authors have precisely described the updates in this area of research.

2. Response of chickpea plants to heat stress

2.1 Physiological basis of heat tolerance in chickpea

Physiological and biochemical analysis under high temperature treatments both in vivo and in vitro provide better mitigating strategies in chickpea [9, 10]. Physiological processes including primary and secondary metabolism, photosynthesis, lipid and hormone signaling are affected greatly due to high temperature environments [11]. Sensitive genotypes of chickpea displayed reduced leaf water content, membrane stability and chlorophyll content with a greater impact compared to the tolerant genotypes. Contrarily, tolerant genotypes had better antioxidant capacity and high accumulation of osmolytes with minimum oxidative damage [12].

Photosynthesis is the main event related to plant productivity and considered as essential for crop improvement investigations. Decrease in photosynthesis and carbon metabolism associated proteins were found to be a major consequence of high temperature stress in plants [13]. Upregulation of proteins associated with photosynthesis and energy metabolism includes NDH-2-platoquinone reductase, photosystem b compounds, larger subunits of Rubisco, ribosomal proteins and ATP synthase were found in tolerant genotypes in order to provide more energy under high temperature conditions. Similarly, heat shock proteins, ethylene receptor- like proteins, MAP kinases and NBS-LRR proteins were upregulated in the tolerant genotypes of chickpea under heat stress [12].

2.2 Biochemical basis of heat tolerance in chickpea

Electrolyte leakage and accumulation of malondialdehyde (MDA) and hydrogen peroxidase (H_2O_2) were found to be high in sensitive genotypes of chickpea compared to tolerant one indicating heat induced lipid per oxidation and membrane damage. In tolerant genotypes, proline content, soluble sugars, antioxidant activity and osmolyte accumulation were reported to be in increase fold [12]. Bhatnagar-Mathur *et al*. [14] suggested that enhancement of osmoprotectants accumulation could be a mitigating strategy chosen by tolerant chickpea plants to withstand heat stress. Acetyl-CoA carboxylase, pyrrolinei-5-carboxylatei synthase (P5CS), Ribulose-1, 5-bisphosphate carboxylase (Rubisco), phenylalaninei ammonia lyase 2 (PAL), ATP synthase, glycosyltransferase, sucrose synthase and leaf embryogenesis abundanti (LEA) are the enzymes strongly connected to heat tolerance in chickpea [12].

A significant reduction in sugar content to increase carbon availability and osmoprotection during stress adaption was reported in tolerant genotypes by Kaushal *et al*. [10]. Methyl-tetra-hydropteroyl-triglutamate–homocysteine methyltransferase, delta-1-pyrroline-5-carboxylate synthase (P5CS), phenylalanine ammonia-lyase were the key enzymes involved in various amino acid synthesis in chickpea plants to tolerate heat stress [12]. Reduction in accumulation of carbohydrates and modified source-sink dynamics in pollen grains causes pollen viability loss and reduced yield in chickpea under heat stress [15]. Similarly, reduction in soluble sugars in the walls of anther eventually decreases the pollen development and viability during high temperature conditions [10]. Sucrose synthase is a key enzyme for heat stress tolerance. A prominent expression of the enzyme at mRNA and protein levels was associated with heat stress tolerance in Chickpea [16].

2.3 Molecular basis of heat tolerance in chickpea

Plants in-built attempts to reprofile their proteins to safeguard the metabolic processes that help plants to survive and function under stress condition [17]. Exploiting plant genotypes at molecular level for heat sensitivity can provide better understanding of mechanisms that associate with heat tolerance in plants. Proteomic profiling in food legumes have been minimal. Proteomics data of genotypes to high temperature response will be highly useful for better understanding of heat stress mechanism [18]. Echevarria-zomeno *et al*. [19] implicated proteomic approaches successfully to elucidate heat stress responses.

Parankusan *et al*. [12] studied proteome profiling and pathway analysis in chickpea, revealed that osmoprotectants accumulation, secured membrane transport, secondary metabolite production, ribosome function, activation of antioxidant compounds, amino acid synthesis and hormonal balance are the effective mitigating strategies which plays vital role in high temperature tolerance. Based on the results of quantitative proteomic analysis of the study, the expressed proteins were grouped into two classes: 1) heat responsive proteins with differential regulation common to chickpea genotypes and 2) genotype specific proteins in tolerant ones under heat stress. The variation in expression patterns of peroxidase isoforms are proposed to be involved in several physiological and stress responses [20].

3. Conclusion

The challenge of climatic changes with exponential rise in atmospheric temperature, is still being a threat for agriculture crops cultivated in arid and semi-arid regions. The overall habitual growth and development of the crop plants can be completely impaired due to heat stress leading to decrease in their production potential. High temperature stress causes several modifications at cellular and sub-cellular levels, which result in protein denaturation, membrane damage and inactivation of enzymes. Increase in exposure of chickpea to heat stress in terms of intensity and duration greatly reduce the yield potential of the crop. Functional measures are required to overcome the negative effects of high temperature stress in chickpea. Therefore, determination of physiological, biochemical and molecular responses of crop to heat stress is essential for improvement of crop status. Study on the nature of signaling cascades, biochemical pathways, physiological dissection and gene expression at molecular level will be important for developing tolerant genotypes under high temperature conditions. Engineering plants to synthesize growth promoting compounds through molecular approaches help in development of crop varieties capable for tolerating high heat and produce greater economic yields. However, the current research on thermotolerance are usually short term and limited to laboratory conditions. Incorporation of biochemical and molecular approaches at field level experiments are needed to study the exact heat stress responses and their effects on crop production.

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