

Effect of water stress on morphological, physiological, biochemical and molecular responses of plants: A Review

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ABSTRACT

Drought is the most important abiotic factor which results in decrease in plant growth and plant productivity. Every plant is exposed either directly or indirectly to drought stress which triggers a wide variety of plant responses. Drought stress seriously affects on plant physiology, biochemistry and molecular mechanism of the plants. Plant develops some mechanism to cope up with the changes. Plant also uses morphological, physiological and biochemical adaptation to mitigate the effect of drought stress. Degree of stress mainly depends on which mechanism plant uses to cope up with the challenge. However, the negative impacts caused by drought is expected, particularly in the case of forest species, because climate change is causing longer and more frequent periods of water deficit, reducing the viability of areas for planting trees. From ecophysiology to cell metabolism, there were several studies on effect of drought. This review is focused mainly on information about the effects of drought on plant growth, physiology as well as plant nutrients and gene expression studies.

Key words : Drought, Physiochemical responses, Biochemical responses, Gene expression

Introduction

Drought is one of the main risks associated with global warming. But there is no generally-approved, specific definition of drought. Possibly the most commonly accepted definition of drought is offered by Beran and Rodier (1985) - 'Drought is reduction in water availability in a specific time and on a specific region'. Thus, drought occurs when an essential water shortage expands both in time and area (Tsakiris and Vangelis, 2004). Drought is intensifying due to global warming and climate change. In addition to this, the growing world population limits the availability of water. In recent years, under-

standing the effects of drought on plants has become a very important matter for improvement of plant breeding and management techniques in agriculture and in determination of the fate of natural vegetation in the environment as water is vital for all known forms of life. When the soil water content decreases, soil moisture is decreased, thus inadequate supply of water to the plant effects on its growth and survival. Every plant is directly or indirectly affected by drought. Plants also use morphological, physiological, biochemical, and molecular mechanisms to avoid drought stress, but this mechanism varies from species to species. From ecophysiology to cell metabolism, there were several

studies on effect of drought (Shinozaki and Yamaguchi, 1997; Dekov *et al.*, 2000; Chaves and Oliveira, 2003). This review is focused mainly on information about the effects of drought on plant growth, physiology as well as plant nutrients and gene expression studies.

Drought Stress Effect on plant morphology

Drought stress affects plant morphological characteristics, such as plant height, leaf size, leaf area, stem diameter, and number of leaves per plant. Mitosis is impaired under drought stress and cell elongation and development are the main causes of plant height, leaf area and growth reduction (Nonami, 1998; Kaya *et al.*, 2006; Hussain *et al.*, 2008). Plant growth mainly occurs in meristematic region. Meristematic regions are the key places where mitosis occurs. Thus drought effects the plant growth by causing alteration in this region. The suppression of plant height is mainly due to the reduction of cell swelling and elongation (Manivannan *et al.*, 2007; Jaleel *et al.*, 2007). Due to rhythmic changes in plant cells, the stem diameter is reduced (Simonneau *et al.*, 1993). The number of leaves of each plant is affected by water stress. Abdelmula and Sabei (2007) concluded that the number of leaves of each plant is basically not affected by drought, but mainly controlled by genetic factors.

Compared with water-sufficient conditions, the stem length of soybeans under drought stress decreased slightly (Specht *et al.*, 2001). Drought stress also decreased the fresh and dry matter weight significantly (Bettaieb *et al.*, 2009). Water stress caused a significant decrease in the height, leaf number, leaf area index, fresh weight and dry weight of cotton, some Cucurbitaceae members (Timpa *et al.*, 1986; Akinci and Losel, 2009, 2010). In another study leaf area decreased approximately 30% in cotton under water stress (Karademir *et al.*, 2012). Drought stress significantly reduced the height of seedlings in populations *Quercus brantii* (Jafarnia *et al.*, 2018). Water deficit reduced the leaf areas of many plant species like soybean (Zhang *et al.*, 2004). During the vegetative period, drought stress resulted in shorter plants and smaller leaf areas of mint (*Mentha arvensis*), yarrow (*Achillea millefolium*) and chicory (*Cichorium intybus*) (Taheri *et al.*, 2009).

There were significant differences in the number of leaves, total leaf area and total biomass of the two poplar sibling populations (Wullschleger *et al.*, 2005). The reduction in leaf area due to drought

stress is considered to be a drought adaptation mechanism, whereby plants avoid dehydration. Similarly, Alishah *et al.* (2006) proved that soil water stress of purple basil (*Ocimum basilicum*) resulted in a significant decrease in plant height, stem diameter, number and area of leaves, and leaf area index. Khorasaninejad *et al.* (2011) also observed significant reduction in growth parameters of peppermint (*Mentha piperita* L.) under water stress. In *Salvia miltiorrhiza*, plants with severe water shortage produce thinner stems with fewer leaves than those of the control, dry and small. Water stress reduced plant height, with the severe stress being more deleterious than mild stress. In the case of moderate water shortage, the plant growth attributes (height, fresh weight and dry matter weight) and the production components of cumin (*Cuminum cyminum*) increased significantly, and these parameters were adversely affected under severe water stress (Bettaieb *et al.*, 2012).

Drought Stress Effect on Photosynthesis

Drought stress reduces photosynthesis by reducing leaf area and photosynthetic rate per leaf area. Reduced leaf expansion, impaired photosynthesis mechanisms, premature leaf senescence and related reductions in food production (Wahid and Rasul, 2005) are all related to inhibition of photosynthesis. Stomatal closure during drought is the main reason for photosynthesis inhibition. The increase of gaseous carbon in the leaf and the decrease of leaf cell water potential are the two main reasons for stomatal closure. The closing of the stomata reduces the inflow of carbon dioxide (CO₂). Reducing CO₂ reduces carboxylation and guides more electrons to form reactive oxygen species (ROS). The generation of ROS is one of the earliest biochemical reactions of eukaryotic cells to biological and abiotic stresses. High concentration of ROS causes oxidative damage to photosynthetic apparatus (Asada, 1994; Reddy *et al.*, 2004; Anjum and Blenis, 2008). ROS will seriously damage plants by increasing lipid peroxidation, protein degradation, DNA fragmentation and eventually cell death. Farooq *et al.* (2009) reported a decrease in photosynthetic rate due to phosphoenolpyruvate carboxylase, ribose-1,5-bisphosphate carboxylase/oxygenase, NADP-malicenzyme, fructose -1,6-bisphosphatase and also the activity of pyruvate orthophosphate dikinase is reduced. Purwanto (2003) also reported that as water stress increases, the photosynthetic rate de-

creases. In *Calotropis* plant photosynthetic machinery was not affected by low water regime, thus well adapted to water deficit stress (Abdellah, 2009). Similar studies in cotton plant reported same result (Massacci *et al.*, 2008).

Drought Stress Effect on Transpiration

Stomatal closure during drought is the main reason which reduces transpiration (Silva *et al.*, 2003, 2009). Some studies have shown that stomata respond to chemical signals, that is, abscisic acid produced by dehydrating roots, while keeping the state of leaf water unchanged (Morgan, 1990; Taylor, 1991; Turner *et al.*, 2001). Borel *et al.* (2001) reported droughted root can contribute abscisic acid (ABA) to xylem sap, and that ABA in xylem sap can close stomata. Decrease transpiration rate reduces the nutrient uptake from the root and thus changes in metabolic pathways. Chaudhury *et al.* (2016) reported a decrease in transpiration rates for four soybean genotypes. Under pressure, the reduction of transpiration may be considered as a drought avoidance mechanism for French bean (Islam *et al.*, 2004). Decrease in the rate of transpiration was reported with *Zea mays*, *Sorghum vulgare*, *Pinus halepensis*, *Triticum kotschyi* and *Triticum aestivum* in relation to leaf water potential (Beadle *et al.*, 1973; Melzack *et al.*, 1985; Johnson *et al.*, 1987). Increasing water stress causes *Themeda triandra* to have a linear decrease in transpiration rate, and the plant attempts to maintain high leaf water potential (Snyman, 1993). Decreased transpiration rate was reported in teak when increasing water stress (Rajendrudu and Naidu, 1997).

Drought Stress Effect on Stomatal Conductance

The stomatal conductance indicates the degree of CO₂ and water vapor exchange between the surrounding blades and the inner blades. It is a measure of the degree of stomatal opening and can be used as an indicator of plant water status. Garnier and Berger (1985) reported in Peach Tree that the stomatal conductance decreased linearly as the average water content of the upper 60 cm soil layer decreased. Mutava *et al.* (2015) revealed that stomatal conductance is the cause of the decrease in soybean photosynthetic rate. Angelopoulos *et al.* (1996) reported that the stomatal conductance of olive trees may limit the photosynthesis of plants grown under moderate drought stress, but under severe drought conditions, non-stomatal factors

have an inhibitory effect on photosynthesis. Makbul *et al.* (2011) also observed that soybean leaves reduced stomatal conductance due to water stress. They reported that drought exposure caused the stomatal conductance of leaves under drought stress to be reduced by 42% compared to unstressed leaves. Mafakheri *et al.* (2010) also reported that plants grown under drought conditions have low stomatal conductance to save water.

Drought Stress Effect on Relative Water Content

Relative water content (RWC) is considered to measure the water status of plants (Sinclair and Ludlow, 1986). The differences in drought tolerance between different genotypes mainly reflect changes in plant water status and swelling. Therefore, in many crops, such as barley (Matin *et al.*, 1989), wheat (Schonfeld *et al.*, 1988), and peas (Kimani *et al.*, 1994), RWC has been used as a criterion for selecting drought resistance. In barley (Yuan *et al.*, 2005), tomato (Zgallai *et al.*, 2005) and pea plant (Kumar *et al.*, 2011), a decrease in RWC was observed as water stress increased. Meher *et al.* (2017) reported that under progressive mild and severe water stress, the RWC of peanut leaves and roots decreased. It is reported that RWC under progressive mild stress is higher than that under severe stress, indicating that the plant has the ability to maintain water under mild stress, but this ability is lost under severe stress treatment.

Drought stress effect on Water Use Efficiency

Water use efficiency (WUE) is the ratio between physiology (transpiration and photosynthesis) or agronomy (yield and crop water use) (Blum, 2005), and is mainly regarded as a feature to avoid drought. Michihiro *et al.* (1994) pointed out that the water use efficiency of drought-tolerant wheat varieties increased, while the water use efficiency of drought-sensitive varieties decreased. Abbate *et al.* (2004) concluded that in the case of limited supply, the water use efficiency of wheat is higher than the condition of sufficient water supply. The higher water use efficiency is mainly related to the stomata closure, which will reduce transpiration. The water use efficiency of clover (*Trifolium alexandrinum*) is increased due to low water loss due to reduced transpiration rate and leaf area and a relatively small decrease in yield under drought stress (Lazaridou and Koutroubas, 2004). In *Pinus ponderosa* and *Artemisia tridentata*, drought stress did not reduce water

use efficiency. Rather, the stomatal conductance decreases rapidly with increasing water deficit (DeLucia and Heckathorn, 1989). Lazaridou and Noitsakis (2003) reported that under the same leaf water potential, the water use efficiency of Lucerne (*Medicago sativa*) under drought conditions is higher than that under irrigation conditions. In some studies, drought stress has greatly reduced water use efficiency, leading to a decline in growth and biomass accumulation (Costa *et al.*, 1997).

Drought Stress Effect on plant Biomass, Root Shoot Ratio, Specific Leaf Area and Leaf Area Ratio

Plants exhibit different phenotypic changes to minimize the negative effects of harsh environments (Kathiresan *et al.*, 2006; Nicotra *et al.*, 2010). Drought significantly increased root mass scores, but decreased stem, leaf, and reproductive quality scores (Eziz *et al.*, 2017). Plants use their adaptive mechanism to avoid water stress by promoting greater relative carbon allocation to root growth, which ultimately result in higher root-to-shoot ratio (Kozłowski and Pallardy, 2002). Root-to-shoot ratio (R/S) and shoot-to-root ratio are commonly used to estimate the relative biomass allocation between root and shoot (Wilson, 1988; Gowda *et al.*, 2011; Poorter *et al.*, 2012). Some studies report that dry weight decreases under drought stress, but the root-to-shoot ratio increases (Xu *et al.*, 2015). It is believed that the distribution of carbohydrates between shoots and roots may be related to changes in R/S (Xu *et al.*, 2015). Buds are metabolically inactivated to reduce the consumption of water and nutrients, while roots are metabolically activated to enhance the absorption of water and nutrients, thereby maintaining the effects of drought (Gargallo-Garriga *et al.*, 2014). In Olive trees, no significant difference was observed in leaves dry weight but in the roots and stem dry weight, a significant difference was observed (Boussadia *et al.*, 2018). In their study, there were no significant differences between treatments for the root part/aerial part ratio. Drought significantly reduced the total dry weight of two *Populus przewalskii* populations (Yanbao *et al.*, 2006). In their study, drought also significantly affected the distribution of dry matter to the root system. Compared with humid climates, arid climate populations show lower dry matter accumulation and relatively higher root allocation. Severe water stress

resulted in increases in the root-to-shoot ratio of ponderosa pine seedlings (McMillin and Wagne, 1995). There was no significant difference in the root cap length and biomass ratio of large solid seedlings under different treatment methods (Sneha *et al.*, 2012).

Specific leaf area determines how much new leaf area to deploy for each unit of biomass produced. It is the ratio of total leaf area to total leaf dry mass. Thicker leaves with a smaller leaf area can increase the conversion rate of available water under drought conditions, thereby increasing yield. Specific leaf area decreased at ample water and increased at low water in sorghum. Under rain-fed and drought conditions, the specific leaf area of maize decreases with the increase of effective accumulated temperature (Zhou *et al.*, 2020). Leaf area ratio measures the efficiency of plants using their leaves to produce plant material. The photosynthetic surface area per unit dry weight of plants mainly determines the leaf area ratio.

Drought stress effect on Proline metabolism

Proline as an osmolyte helps stabilize subcellular structures, such as membranes and proteins (Iqbal, 2009). As an antioxidant, it also has ROS scavenging function and buffering cellular redox potential (Matysik *et al.*, 2002; Smirnov and Cumbes, 1989). Proline is believed to stabilize membrane phospholipids, thereby helping plants overcome periods of drought stress. To restore plants from drought stress, proline acts as a signaling molecule to change mitochondrial function, affect cell proliferation or cell death, and activate specific gene expression (Szabados and Savaourne, 2009). The accumulation of proline may be caused by the activation of proline through the glutamate pathway, which involves γ -glutamyl kinase, glutamyl phosphate reductase and $\Delta\beta$ -pyrroline-5- Carboxylic reductase activity (Bray, 1990). Cvikrova *et al.* (2012) studied the role of proline and polyamines (PAs) in response to drought stress in tobacco plants showed elevated levels of proline. The accumulation of proline was evaluated in four tobacco varieties with different drought tolerance as a criterion for selecting drought tolerance (Rensburg *et al.*, 1993). It has been reported that the accumulation of proline under water stress in sorghum (Yadav *et al.*, 2005), sweet pepper (Nath *et al.*, 2005), upland cotton (Ronde *et al.*, 2000), wheat (Hamada, 2000), and *Catharanthus roseus* (Jaleel *et al.*, 2007). During water

stress, the metabolism of free proline in cassava was found to have changed (*Manihot esculenta*), and the degree of change varied with drought and drought-tolerant varieties (Sundaresan and Sudhakaran, 2006). Also Baher *et al.* (2002) reported that the accumulation of free proline in *Satureja hortensis* L. increased under drought stress. Excessive production of proline can maintain cell filling or osmotic balance; stabilize the membrane, thereby preventing electrolyte leakage; and keep the ROS concentration within the normal range. Since proline act as a molecular chaperone, it can maintain protein integrity and enhance the activity of different enzymes (Hayat *et al.*, 2012; Rajendrakumar *et al.*, 1997).

Drought Stress Effect on Chlorophyll Content

The chlorophyll content of plant is affected and prevented to make under drought stress (Lessani and Mojtahedi, 2002). The change of chlorophyll content mainly depends on the stress rate and duration (Rensburg and Kruger, 1994; Kyparissis *et al.*, 1995; Jagtap *et al.*, 1998). The reason for the reduction of chlorophyll is mainly due to the production of reactive oxygen species, such as O₂ and H₂O₂, which cause lipid peroxidation, thereby destroying chlorophyll (Mirnoff, 1993; Foyer *et al.*, 1994). As the green leaf color changes to yellow, the result is that as the chlorophyll content decreases, the reflectance of the incident radiation increases (Schelmmmer *et al.*, 2005). This mechanism protects photosynthesis system during stress. Chlorophyll content is the main component of chloroplast, so chlorophyll content is positively correlated with photosynthetic rate. Some studies have reported that lack of water can damage leaf pigments (Montagu and Woo, 1990; Nilsen and Orcutt, 1996). In sesame plants, drought stress increases chlorophyll and then remains unchanged (Mensah *et al.*, 2006). Beeflink, etc. (1985) reported an increase in chlorophyll in onions under drought stress. Fotovat *et al.* (2007) found that by applying severe drought stress to wheat, the chlorophyll content of the leaves was significantly reduced. Drought stress caused a significant reduction in chlorophyll a, b and total photosynthetic pigments in soybean leaves (Mannan *et al.*, 2016; Ladjal *et al.*, 2000; Younis *et al.*, 2000; Terzi *et al.*, 2010). In Tunisian olive varieties (*Olea europaea* L.) water deficit decreased the level of chlorophyll (a+b) (Guerfel *et al.*, 2009). The level of chlorophyll and chlorophyll a+b ratio were not affected by drought in some

studies (Munne-Bosch *et al.*, 2001).

Drought Stress and Plant Nutrition

Understanding the concentration of elements under drought stress may help predict plant growth and development. Under drought stress, soil moisture is mainly reduced, and the closure of stomata leads to a reduction in transpiration, thereby reducing water transport in plants. In turn, it affects the ability of roots to absorb moisture and nutrients in the soil (Waraich *et al.*, 2011). Thus decrease in transpiration rate, imbalance of active transport and membrane permeability are the main reason in limiting nutrient transport from the root to the shoot (Hu and Schmidhalter, 2005; Hu *et al.*, 2007; Farooq *et al.*, 2009). Drought stress increased the potassium (K), calcium (Ca) and sodium (Na) content of *Ricinus communis* L. plants, while the iron (Fe), copper (Cu), zinc (Zn) and magnesium (Mg) content decreased (Tadayyon *et al.*, 2017). Significant differences in nutrient level were also observed among different olive cultivars (Kumar and Sharma, 2016). Drought usually increases N, K, Ca, Mg, and Cl, but decreases phosphorus (P) and iron (Rahman *et al.*, 1971). It has been reported that water stress mainly reduces the absorption of calcium, iron, magnesium, nitrogen, phosphorus and potassium in *Spartina alterniflora* (Brown *et al.*, 2006). In *Dalbergia sisoo* leaves drought stress reduced Fe, K, Cu and increased N, P, Ca, Mg, Zn and Mn with increasing water stress (Nambiar, 1977). In forage plants and alfalfa (*Onobrychis viciifolia* Scop.), nutrient elements increased under drought stress (Gerakis *et al.*, 1975; Kidambi *et al.*, 1990). Drought-induced nitrogen deficiency largely limits the growth of plants under water-scarce conditions (Heckathorn *et al.*, 1997). Under water stress conditions, it has been noted that enzymes related to NO₃ assimilation have changed in plants under water stress conditions (Larsson *et al.*, 1989; Kaiser and Bendle-Behnisch, 1991; Kenis *et al.*, 1994; Brewitz *et al.*, 1996). P deficiency under drought causes reduction in stomatal conductance and regeneration capacity of ribulose 1, 5 biphosphate (RuBP) which in turn reduce photosynthetic rate (Brooks, 1986) and thus results in diminished relative leaf-growth rate (Kirschbaum and Tompkins, 1990). Thus lack of nutrient availability due to improper transport mechanism under drought effect badly at the whole plant level and thus fails to grow adequately.

Gene Expression Study Under Drought

When the soil water content is reduced, the plant faces a water shortage of cells. Under extreme water scarcity conditions, gene expression will change. During drought, some genes are up-regulated and down-regulated. Genes are mainly caused by drought at the transcription level. Global transcriptome analysis provides an opportunity to gain a deeper understanding of the complexity of plant response to drought stress at the molecular level. There are several reports on global gene expression studies in plant mainly in crop species during drought stress. It was originally known to isolate many known genes related to stress tolerance in *Arabidopsis* (Matsui *et al.*, 2008). Drought responsive genes were mainly identified and functionally categorized in some model plant species. But there are few reports on drought responsive gene in non model plant. The response to drought was analyzed in leaves and root tips and compared with available transcriptome data from *Populus* species (Cohen *et al.*, 2010). The transcriptome of the leaf seems to respond weaker to drought than the transcriptome of the root tips.

Transcriptome information under drought stress is helpful to study gene expression in many conifer species such as *Pinus pinaster* (Canas *et al.*, 2015) and *Pinus menzeisii* (Muller *et al.*, 2012). Drought also caused significant changes in the expression of certain functional genes related to osmotic regulation (P5CS), abscisic acid (ABA) responses (NCED, PYL, PP2C and SnRK) and reactive oxygen species (ROS) clearance (GPX, GST and GSR) in *Pinus massoniana* (Mingfeng *et al.*, 2018). Several transcription factors (TF) related to circadian rhythms (HY5 and LH1), signal transduction (ERF) and defense response (WRKY) may play a key role in adapting to drought stress. Transcriptional profiling and gene expression analysis of some non-model plant jujube (*Ziziphus nummularia* Burm.f.) under drought stress according to reports (Yadav *et al.*, 2018). Transcriptome analysis of the tea oil *Camellia oleifera* reported 76,585 unigenes where 52,531 unigenes were functionally annotated (Dong *et al.*, 2017). Gugger *et al.* (2016) reported gene expression profiles in California oak species, *Quercus lobata* under drought. These reported genes have stress response (WRKY DNA binding protein 51 and HSP20-like chaperone superfamily proteins), metabolism (phosphoglycerate kinase and protein kinase superfamily proteins),

transport/transport (cationic amino acid transporter 7 and K⁺ Transporter) and regulatory functions. (WRKY51 and Homeodomain-like transcriptional regulator).

Gene expression profiling helps in understanding the molecular mechanism during environmental stress. To study drought stress-induced transcription, sequencing techniques have been used in many plant species, including coffee (Mofatto *et al.*, 2016), cassava (Hu *et al.*, 2015), sorghum (Fracasso *et al.*, 2016), and peanut (Brasileiro *et al.*, 2015), corn (Xu *et al.*, 2014) and rice (Wang *et al.*, 2007). Due to the large genome size in trees, sometimes it is very challenging for the researchers to sequence the whole genome. Therefore, to reduce the complexity of analysis and minimize the cost of sequencing, candidate genes provide valuable tools for expression studies. Differential expression analysis revealed 296 candidate genes for drought stress in *Abies alba* (247 up-regulated and 49 down-regulated) (Behringer, 2015). They reported a new reference gene, TPC1, for the analysis of expression profiles of drought stress in the needles of conifer seedlings.

Real time (RT) quantitative Polymerase Chain Reaction (PCR) is mostly used now-a-days in gene expression studies. The use of stable reference genes is the most common method of RT-qPCR data standardization. Under drought stress, the expression profiles of eight internal control genes, namely elongation factor-1 α (EF1 α), actin, tubulin, glyceraldehydes 3-phosphate dehydrogenase (GAPDH), adenine phosphoribosyl transferase (APRT), 60S ribosomal protein L8 (L8), Cullin 3A and component sec3 (sec3) in potato. Under drought and osmotic stress conditions, EF1 α and sec3 are the most stable genes expressed in potato (Tang *et al.*, 2017). Similar studies have been reported in durum wheat under drought and salt stress conditions. Under drought stress, the most stable reference genes are glyceraldehydes -3 phosphate, ubiquitin and β -tubulin 2, while under salt stress conditions, eukaryotic elongation factor 1- α , glyceraldehyde-3 phosphate and actin were identified as the most stable reference gene (Kiarash *et al.*, 2018).

Complementary DNA (cDNA) microarrays are used for gene expression profiling of *Arabidopsis* (Shinozaki and Yamaguchi, 2007), rice (Wang *et al.*, 2007), maize (Zhang *et al.*, 2005) and other crops. cDNA microarray is a traditional method for gene expression research (Liang *et al.*, 2017). cDNA-AFLP (cDNA amplified fragment length polymorphism),

MASS (Mass scale parallel signature sequencing), especially (Serial Analysis of Gene Expression) SAGE (sequence analysis of gene expression) have been successfully used to study gene expression in higher plants (Fizames *et al.*, 2004 ; Meyers *et al.*, 2004; Calsa and Figueira, 2007; Chen *et al.*, 2007; Leymarie *et al.*, 2007; McIntosh *et al.*, 2007; Song *et al.*, 2007; Ritter *et al.*, 2008).

Study of plant physiological parameters and gene expression profiling are very important tool for selection of improved germplasm under drought stress. Analyzing all the physiological parameters under water stress to select the drought resistant germplasm and then studying the mechanism of drought resistance using whole gene expression study helps to identify the drought responsive genes in that particular species. Physiological parameters including, plant growth, rate of photosynthesis, transpiration, stomatal conductance, relative water content, water use efficiency, plant biomass, root shoot ratio, plant nutrients, proline and chlorophyll content under drought stress will help to screen drought tolerance germplasm from the sensitive one. Understanding the molecular mechanism through gene expression study in non model plant and knowledge of traditional breeding will help the breeders in selection of improved variety. Being a major Teak producing country, there are scanty of report on gene expression pattern of teak under drought. Our aim was to have a comparative expression of transcripts in teak from different selected accessions based on physiological parameters under irrigation treatment of 25%, 50%, 75%, 100 % of field capacity.

Conclusion

Study of plant physiological parameters and gene expression profiling are very important tool for selection of improved germplasm under drought stress. Analysing all the physiological parameters under water stress to select the drought resistant germplasm and then studying the mechanism of drought resistance using whole gene expression study helps to identify the drought responsive genes in that particular species. Physiological parameters including, plant growth, rate of photosynthesis, transpiration, stomatal conductance, relative water content, water use efficiency, plant biomass, root shoot ratio, plant nutrients, proline and chlorophyll content under drought stress will help to

screen drought tolerance germplasm from the sensitive one. Understanding the molecular mechanism through gene expression study in non model plant and knowledge of traditional breeding will help the breeders in selection of improved variety.

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