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## A review: Abiotic stress on transpiration, stomatal diffusive resistance and photosynthetic rate

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#### Abstract

Plant growth and crop yield are majorly affected by cold, drought, salt, and heavy metals. A biotic stress impacts plants to molecular levels from morphological levels and is visible at all phases of plant development where drought occurs. There are three significant stages of plant: vegetative development, pre-anthesis and terminal phase that are impacted by the drought. Plant physiological reactions to stress include wilting of the leaf, abscission of the leaf, decreased leaf region and decreased water loss through transpiration. Under drought stress, crop development facilitates the issue of extreme water use in agriculture to a big extent. Turgor pressure is decreased, which is one of the most delicate Physiological mechanisms that cause cell growth. Thus this review paper describes how different a biotic stresses can pose deleterious impacts on plant photosynthetic machinery including cellular membranes, cell division and cell elongation, biosynthesis of photosynthetic pigments, as well as electron transport chain. It is important to understand the detrimental impacts of various a biotic stresses for better stress management because a comprehensive understanding of plant responses has pragmatic implication for remedies and management.

**Keywords:** Abiotic, stomatal, diffusive, resistance, photosynthetic

#### Introduction

Plants encounter various a biotic stresses due to their sessile nature which include heavy metals, salt, drought, nutrient deficiency, light intensity, pesticide contamination, as well as extreme temperatures. These stresses impose major constraints limiting crop production and food security worldwide. Abiotic stresses primarily reduce the photosynthetic efficiency of plants, due to their negative consequences on chlorophyll biosynthesis, performance of the photo systems, electron transport mechanisms, gas exchange parameters, and many others. A better understanding of the photochemistry of plants under these abiotic stresses can help in the development of pragmatic interventions for managing these stresses. Interestingly, in this review, we provide an overview of insight into different mechanisms affecting the photosynthetic ability of plants in relation to these a biotic factor (Sharma *et al.*, 2020).

Stress is an altered physiological condition caused by factors that tend to disrupt the equilibrium. Strain is any physical and chemical change produced by a stress (Gaspar *et al.*, 2002). The term stress is used with various meanings, the physiological definition and appropriate term as responses in different situations. The flexibility of normal metabolism allows the response initiation to the environmental changes, which fluctuate regularly and are predictable over daily and seasonal cycles. Thus every deviation of a factor from its optimum does not necessarily result in stress. Stress being a constraint or highly unpredictable fluctuations imposed on regular metabolic patterns cause injury, disease or aberrant physiology. Plants are frequently exposed to many stresses such as drought, low temperature, salt, flooding, heat, oxidative stress and heavy metal toxicity, while growing in nature. Drought stress is considered to be a moderate loss of water, which leads to stomatal closure and limitation of gas exchange. Desiccation is much more extensive loss of water, which can potentially lead to gross disruption of metabolism and cell structure and eventually to the cessation of enzyme catalyzed reactions (Smirnoff, 1993; Jaleel *et al.*, 2007). Drought stress is characterized by reduction of water content, diminished leaf water potential and turgor loss, closure of stomata and decrease in cell enlargement and growth. Severe water stress may result in the arrest of photosynthesis, disturbance of metabolism and finally the death of plant (Jaleel *et al.*, 2008)

Plants in natural environments must cope with diverse, highly dynamic, and unpredictable conditions. They have mechanisms to enhance the capture of light energy when light intensity

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is low, but they can also slow down photosynthetic electron transport to prevent the production of reactive oxygen species and consequent damage to the photosynthetic machinery under excess light. Plants need a highly responsive regulatory system to balance the photosynthetic light reactions with downstream metabolism. Various mechanisms of regulation of photosynthetic electron transport under stress have been proposed, however the data have been obtained mainly under environmentally stable and controlled conditions. Thus, our understanding of dynamic modulation of photosynthesis under dramatically fluctuating natural environments remains limited (Yamori 2016) <sup>[37]</sup>.

### **Drought and Heat stress affecting Transpiration and stomatal diffusion**

Drought and heat stress are simultaneously prevalent in semi-arid or drought-stricken areas and have been extensively studied. Still, very little is known about their combined effect on plants (Zhao *et al.*, 2017, Lamaoui *et al.*, 2018). Rate of photosynthesis is a physiological response of a plant under stress conditions that is influenced by stomatal restrictions such as insufficient CO<sub>2</sub> availability, as well as non-stomatal restrictions like decreased electron transport capacity and RuBisCO activity. However, concurrence of drought and heat stress can lead to impairment of Photosystem II, reduced RuBisCO activity, increased leaf temperature, reduced stomatal conductance and diminished concentrations of photosynthetic pigments. Raja *et al.* (2020) reported that the chlorophyll and carotenoid concentrations decreased by 80% and 57% respectively in tomato plants under the influence of both drought and heat stress. Drought and heat stress together also affect pistil and pollen development, ovule functions and grain weight (Prasad *et al.*, 2011). Apart from this, there is overproduction of ROS resulting in denaturation of proteins and lipid peroxidation, reduced nutrient uptake, impairment of membrane structure and hampered plant growth and yield. Drought and heat stressed maize plants showed significantly increased levels of ROS and malondialdehyde, declined activities of antioxidant enzymes like catalase and ascorbate peroxidase, reduced nutrient uptake, shortened root and shoot length and decreased grain and kernel yield (Hussain *et al.*, 2019).

A plant's response to co-occurrence of drought and heat stress is further complexed by its prioritization for the more serious stress. For example, under drought conditions, stomata are closed prematurely by the plant to prevent water loss, while under heat stress there is increased stomatal conductance to cool down the temperature of leaves through transpiration (Rizhsky *et al.*, 2004). Rizhsky *et al.* (2002) demonstrated that tobacco plants when subjected concurrently to drought and heat stress, exhibited higher leaf temperature in comparison to plants subjected to heat stress alone due to the precedence of stomatal closure to reduce water loss over the need to cool the leaves by keeping them open. Similarly, accumulation of osmo-protectants is different under drought stress where proline is one of the major osmoprotectants that aggregates in plants, whereas no accumulation of proline is reported under heat stress conditions. Moreover, under conditions of combined stress, proline accumulation is found to be toxic and sucrose is the main osmoprotectant that accumulates (Mittler, 2006, Cohen *et al.*, 2020).

### **Salinity Stress affecting Stomatal diffusion**

Salinity in water or soil is another abiotic factor that can limit crop production specifically in arid or semi-arid regions. Shanon *et al.*, (1997). According to an estimate published in 2011, over 800 million hectares of world land are affected by high levels of salinity. Ishayenkov *et al.*, (2012). Similarly, the same study reported that about 17 million hectares of agricultural land will be affected by salinity by 2050. The adverse effects of salinity on plants are associated with the low osmotic potential of soil, nutritional imbalance, specific ion effect, or a combination of all these factors. Ashraf *et al.*, (1994) <sup>[2]</sup>. These factors have severe effects on plant growth and development at various levels. Levitt *et al.*, (1980) <sup>[18]</sup>. General effects include reducing the growth rate, smaller and fewer leaves, and reduction in root length Munns *et al.*, (1986) <sup>[24]</sup>. The osmotic effect of salinity contributes to changes in leaf color and developmental aspects such as root/shoot ratio and maturity rate Shanon *et al.*, (1989). As with other abiotic stresses, the effects of salinity on plants and their response towards it depends on the duration and severity of the stress. Generally, salinity has short term effects (such as ion-independent growth reduction) that take place within minutes to hours or days after perception of the stimuli, close stomata and inhibition of cell expansion which is shoot specific Munns *et al.*, (2008) <sup>[26]</sup>, and long-term effects which can occur over days or even weeks (such as building up cytotoxic ion levels, slowing down the metabolic activities and causing early senescence and ultimately cell death) Roy *et al.*, (2014) <sup>[30]</sup>. A plant's tolerance to salinity is achieved by a multitude of physio-molecular mechanisms, osmotic and ionic tolerance, and tissue tolerance Rajendra *et al.*, (2014). Among these, osmotic tolerance is a rapid response associated with a quick decrease in stomatal conductance to store water which employs fast signaling mechanisms between roots and shoots [Roy *et al.*, (2014) <sup>[30]</sup>, Rajendra *et al.*, (2014)]. The ionic tolerance is achieved by activation of several signaling cascades that restrict net Na<sup>+</sup> influx and reduce net Na<sup>+</sup> translocation. Isayenkov *et al.*, (2019). The tissue-specific tolerance is achieved by translocation of toxic ions to the vacuole to avoid their detrimental effects on cytoplasmic-based metabolic processes Isayenkov *et al.*, (2019). The salt overly sensitive (SOS) pathway comprising of different SOS genes, in this case, is the key to direct toxic ions to the vacuole Ji *et al.*, (2013).

### **Heavy metal stress affecting Photosynthetic rate**

Heavy metal stress (HM) belongs to a group of non-biodegradables, determined inorganic chemicals having atomic mass more than 20 and a density exceeding 5 g cm<sup>-3</sup> with toxic effects on cells and genes, which causes mutagenic impacts on crops by influencing and contaminating irrigation, soil, drinkable water, food chains and the surrounding environment Flora *et al.*, (2008) <sup>[11]</sup>, Wuanna *et al.*, (2011). There are two categories of metals discovered in soils that are mentioned as vital micronutrients for standard plant growth (Fe, Mg, Mo, Zn, Mn, Cu, and Ni) and non-essential elements with unknown physiological and biological function (Ag, Cr, Cd, Co, As, Sb, Pb, Se, and Hg) Schutzendubel *et al.*, (2002) <sup>[31]</sup>. Plant surfaces both underwater and above ground can take HMs. In the enzyme and protein structure, the vital elements play a main role.

Plants need them in minute quantities for their metabolism, growth, and development; yet, the concentration of vital and non-essential metals is an only essential factor in the increasing crop cycle so that their excessive presence can cause a decline and inhibition of plant growth. HMs at poisonous concentrations hinder ordinary functioning in plants and act as an barrier to metabolic procedures in different ways, comprising the displacement or disturbance of protein structure construction blocks arising from the creation of bonds among HMs and sulfhydryl groups Hall *et al.*, (2002) <sup>[13]</sup>, interfering with functional groups of significant cellular molecules Hossain *et al.*, (2015) <sup>[14]</sup>.

The photosynthetic rates decreased for all poplar hybrids across all heavy metal concentrations; however, only hybrid 1 (Eco 28) had a high photosynthetic rate at 500 ppm. Decline in photosynthetic rate has been exhibited in other plants, due to the reduction in photosynthetic pigments by the heavy metals. Heavy metals such as mercury (Hg), Cu, Cr, Cd, and Zn have been found to decrease the chlorophyll content in various plants in most cases (Aggarwal *et al.* 2012) <sup>[1]</sup>. This decline in photosynthetic pigments is most probably due to the inhibition of the reductive steps in the biosynthetic pathways of photosynthetic pigments due to the high redox potential of many heavy metals. In addition, the key enzyme, protochlorophyllide reductase, which is involved in the reduction of protochlorophyll to chlorophyll is well known to be inhibited by heavy metals (De Filippis and Pallaghy 1994) <sup>[5]</sup>. Various authors have reported similar decreases in chlorophyll content under heavy metal stress in cyanobacteria, unicellular chlorophytes (*Chlorella*), gymnosperms such as *Picea abies* and angiosperms, such as *Zea mays*, *Quercus palustris* and *Acer rubrum*, sunflower as well as almond (Siedlecks and Krupa 1996; Zengin and Munzuruglu 2006; Elloumi *et al.* 2007) <sup>[38, 8]</sup>. A few reports show an enhancement of pigments after exposure to heavy metals (Devi Prasad and Devi Prasad 1982) <sup>[7]</sup>.

### Biochemical and photochemical limitations to photosynthetic rate

Changes in leaf biochemistry that result in down-regulation of the photosynthetic metabolism may occur in response to lowered carbon substrate under prolonged stresses (Chaves and Oliveira, 2004; Flexas *et al.*, 2006b) <sup>[3, 10]</sup>. For example, a de-activation of the carboxylating enzyme Rubisco by low intercellular CO<sub>2</sub> (C<sub>i</sub>) has been observed (Meyer and Genty, 1998) <sup>[12, 22]</sup>. Following stomatal closure and the fall in CO<sub>2</sub> concentration in the intercellular airspaces of leaves, other enzymes have been shown to decrease their activity (e.g. SPS or nitrate reductase); this change was quickly reversed when increasing CO<sub>2</sub> in the surrounding atmosphere (Sharkey *et al.*, 1990) <sup>[35]</sup>. Early biochemical effects of water deficits that involve alterations in photophosphorylation (a decrease in the amount of ATP leading to a decreased regeneration of RuBP) have also been described (Tezara *et al.*, 1999) <sup>[36]</sup> and seem to be dependent on species showing different thresholds for metabolic down-regulation (Lawlor and Cornic, 2002) <sup>[17]</sup>. Under salt stress, metabolic limitations of photosynthesis resulting from increased concentrations of Na<sup>+</sup> and Cl<sup>-</sup> in the leaf tissue (in general above 250 mM) do occur (Munns *et al.*, 2006) <sup>[23]</sup>. As previously pointed out the fast changes in gene expression following stress imposition that have been observed, suggest that alterations in metabolism start very early.

When, in addition to drought and salinity, plants are subjected to other environmental stresses such as high light and temperature either chronic (under high and/or persistent excess light) or dynamic (under moderate excess light) photoinhibition is likely to occur. In fact, under those conditions that limit CO<sub>2</sub> fixation, the rate of reducing power production is greater than the rate of its use by the Calvin cycle. Protection mechanisms against excess reducing power are thus an important strategy under water stress. These photoprotective mechanisms compete with photochemistry for the absorbed energy, leading to a decrease in quantum yield of PSII (Genty *et al.*, 1989). Such protection may be achieved by the regulated thermal dissipation in light-harvesting complexes, somehow involving the xanthophyll cycle (Demmig-Adams and Adams, 1996) <sup>[6]</sup> and the lutein cycle (Matsubara *et al.*, 2001) <sup>[21]</sup>. Although its role is not totally clear yet, photorespiration may also be involved in protecting the photosynthetic apparatus against light damage as suggested by its increase under drought observed in several species (see the review by Chaves *et al.*, 2003) <sup>[4]</sup>. Photorespiratory-produced H<sub>2</sub>O<sub>2</sub> may also be responsible for signalling and acclimation under restricted CO<sub>2</sub> availability (Noctor *et al.*, 2002) <sup>[27]</sup>. In addition to the photoprotective mechanisms that may use intercepted solar radiation that is not utilized by photochemistry, the avoidance mechanisms resulting from leaf or chloroplast movements known as 'paraheliotropism', that are very effective in reducing intercepted radiation, cannot be disregarded. The masking of chlorophyll by anthocyanins that prevent photo-oxidative damage to leaf cells is particularly important in senescing leaves since it allows an efficient nutrient retrieval from those leaves to the storage compartments of the plant (Feild *et al.*, 2001) <sup>[9]</sup>.

### Conclusion

The ability of plants to be able to regulate the size of the stomatal opening is a very important mechanism to control water loss and survive. This ability is especially important during water stress, when loss of water can have serious consequences for the plants. Water stress can cause reduced growth and in severe cases plant death. To minimize the negative effects of water stress the plants respond by changing their growth pattern, producing stress proteins and chaperones, up-regulation of anti-oxidants, accumulation of compatible solutes, increasing the amount of transporters involved in water and ion uptake and transport and by closing the stomata. If the plants are unable to quickly respond to water stress, by closing the stomata and thereby conserve as much water as possible, the consequences are more severe and plants wilt and die more quickly. This is a major problem in plant propagation of ornamentals. Plants developed under high relative air humidity develop malfunctioning stomata, which are unable to close in response to water stress.

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