Review Article

Physiological, Biochemical and Morphological Responses of Plants to Water Deficit Conditions: A Review

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Abstract | It is now universally accepted that global warming is the cause of climatic changes and that it is a major threat for the twenty-first century. The current climate crisis has made water shortage stress worse and limits plant growth and productivity by reducing nutrient uptake and increasing osmotic load. In addition, dramatic climatic changes can reduce water availability, leading to a variety of problems, including the ongoing limited water condition. The present review article intends to critically analyze morpho-physiological and growth, responses of plants to various levels of drought stress as well as their ability to regulate and alleviate the negative consequences of low water availability. Meeting the world's population's continual increase in food consumption is hampered significantly by drought stress. Plants adjust their cellular osmotic potential and water potential in response to stressors, by increasing root length, closing stomata to reduce transpiration and also activating their natural defensive mechanisms by producing anti-oxidative enzymes and accumulating osmoprotectants. Changes in photosynthetic pigments are one of several factors that affect how much water is accessible to plants under scarce water situation. Photosynthetic pigments, antioxidant enzymes and phenolic compounds play a vital role in a plant's capacity to endure drought stress conditions.

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Introduction

Drought: Agricultural output and livelihood is directly affecting owing to the current state of changing climatic conditions, which is posing threats in the form of natural catastrophes, including droughts, severe floods, earthquakes, and temperature variations (Boudiar *et al.*, 2020). Numerous physio-biochemical processes are disrupted by drought stress, which constrains the growth and development of plants (Islam *et al.*, 2020). Although they usually suffer significant losses in total biomass and production, plants can often resist low water circumstances. Around 50% of the semi-arid and arid areas of the world are damaged by water scarcity. Under water limited circumstances, essential physiological and biochemical processes are disrupted (McDowell *et al.*, 2022). According to earlier research oxidative stress brought on by drought stress harms biomolecules. In reply to the stress caused by oxidation, plants produce osmolytes or osmoprotectants such as proline and glycine betaine as part of their natural defensive mechanisms (Ali *et al*., 2022). Osmolytes do not affect other physiological and biochemical processes since they are non-toxic and extremely soluble (Naeem *et al*., 2022). In response to abiotic stress, plants produce antioxidant compounds like polyphenols, vitamins, and antioxidative enzymes (Chai *et al*., 2016). Under water limited supply plants produce reactive oxygen species (ROS) causing oxidative damage and alter leaf gas exchange rates (Alam *et al*., 2021). In addition, plants have well-developed natural drought-resistance mechanisms (Ghafar *et al*., 2021). Drought stress leads to nutritive disparities, thus has a large environmental impact on global farming production. The difficult problem for agricultural production is drought stress, which has a strong detrimental impact on plant development and production, making it a challenge for sustainable global agriculture supply and output (Azeem *et al*., 2022). The effects of drought-induced alterations in wheat traits on agronomic parameters and yield were examined. Limited supply of water has a deleterious influence on spikelet fertility and grain filling (Grzesiak *et al*., 2019). Water stress reduces agricultural productivity and jeopardizes food production (Kamal *et al*., 2019). Lower agricultural productivity results in lower profits for nearby farmers. The livelihoods and economies of farmers are significantly impacted by the loss of production (Boudiar *et al*., 2020).

Plants morphological changes caused by drought

Water is an important component for the germination of seeds, though even under ideal circumstances; drought stress prevents seeds from ingesting water, which prevents germination (Islam *et al*., 2018). Similarly, by reducing water intake, it affects germination and lessens seedling vigor. Both the rice plant and pea plant had low sapling growth when subjected to drought stress (Liang *et al*., 2021). Germination success can be affected by low soil water content in combination with other environmental conditions (Damalas, 2019). The upper epidermal cells of the leaf lose water, which lowers the leaf's potential for pressure, making the leaf roll. This phenomenon is benefited by decreased leaf temperature, higher light absorption, and enhanced transpiration rate (Cai *et al*., 2020). In contrast, it is shown that length of shoot of maize crop needed to be recovered in order to survive and overcome water stressed circumstances (Tumova *et al*., 2018). Similar findings showed that drought stress significantly reduced the height of maize seedlings. The dry weight of maize crops after drying in shadows is significantly impacted by the water scarcity (Bocchini *et al*., 2018). According to the findings, lack of water has a significant influence on the fresh weight of maize when compared with controlled group. Plant require robust root systems in these circumstances so that it may attach to its surroundings and draw moisture and nutrients from them (Begum *et al*., 2019). Water limited conditions changes the shape and architecture of agricultural plants' roots. Many plants experience an increase in root biomass under abiotic stress circumstances as their roots grow longer and take up additional water and raw materials from the soil (Singh *et al*., 2018). Maize plants underwent drought stress induced by polyethylene glycol, which increased root length while reducing the length of hypocotyl (Hu and Chen, 2020). *Catharanthus roseus* L. and *Helianthus anuus* L. were two plants that had their root development accelerated by drought stress, according to earlier studies (Sharma *et al*., 2021). The structure of a plant's roots is essential to its growth and development. Water-stressed conditions cause plants root to extend deeper into soil in search of water and essential nutrient uptake (Wright *et al*., 2001).

Physiological responses to water limited regimes (drought stress)

Due to insufficient water in the land, drought results in water shortages. The physiological drought is not necessarily brought on by a lack of water in the soil (Gupta *et al*., 2020). When a plant does not receive enough water, a physiological drought ensues; plants respond to water stress in different ways (Malinowska *et al*., 2020). In barley plant drought stress frequently resulted reduced leaf water content, turgor pressure decline, and closing of stomata. Abscission of leaves during drought minimizes water loss through transpiration (Wu *et al*., 2022). Plants ability to expand their cells is impaired when there is a severe water scarcity due to the cessation of xylem water flow (Kim *et al*., 2017). During photosynthesis, CO_2 and H_2O inside chloroplasts of turn into carbohydrates and oxygen as byproduct. For photosynthesis to occur, chloroplasts must contain chlorophyll (Ghafar *et al*., 2021). In *Nicotiana tabacum* L., water-stressed conditions during stomatal closure and reopening have an impact on chlorophyll pigments, which are necessary for photosynthesis (Hu *et al*., 2018). For photosynthesis to occur, light must be absorbed and utilized by plants. Due to augmented oxidative pressure, chlorophyll pigment degradation was observed (Wu *et al*., 2022). Reduced stomatal conductance in (*Triticum aestivum* L.) was primarily linked to drought sensitivity, which in turn lowered carbon dioxide supply to chloroplasts and, as a result, decreased net photosynthesis (Soares *et al*., 2019). The findings showed that drought stress reduced photosynthesis, which in turn impaired plant growth and development (Ferrara *et al*., 2011). One of the many environmental factors that hinder photosynthesis is a water deprived state. Drought stress is driven by the susceptibility of linking photosystems to lowering stresses brought on by exterior factors and damages these systems, which are reaction sites (Figure 1). Manufacturing activities may not have been balanced, according to methods of chlorophyll fluorescence (Pourghasemian *et al*., 2020). Plants respond to drought stress by controlling the movement of their stomata, altering its osmotic adjustment potential and developing antioxidant defensive system (Kamran *et al*., 2019). Plant development may be slowed, or plant mortality may occur over an extended period under high-intensity, limited water conditions (Ahanger *et al*., 2018). Photosynthetic system of plants and their pigments are deeply damaged by water scarce condition (Ghafar *et al*., 2021). Closing of the stomata is the initial indicator of stress onset, sugar beet stomata gradually close as drought stress increases during the day (Islam *et al*., 2020). In times of high drought stress, stomata are completely closed. However, as evidenced by pea crops (*Pisum sativum* L.), complete closure differs amongst species according to its individual drought tolerance (Hashmat *et al*., 2021). Since the stomatal system controls carbon rate fixation and other physiological processes, plant species tolerance has an impact on these processes (Figure 2). Additional electrons are offered to form reactive oxygen species under stomatal restriction to exchange CO_2 into the leaves (Yang *et al*., 2021). The pH of leaf sap increases when environmental factors such as increased transpiration rates affect physiological processes (Foyer, 2018). The respiration rate of different plant parts, such as leaves, shoots, and the entire plant, is decreased by drought stress (Wright *et al*., 2001). Plants continue to respire at the same pace or even speed up (Khan *et al*., 2021). When soil dries up too quickly, respiration in roots and total biomass reduction takes place (Djanaguiraman *et al*., 2018).

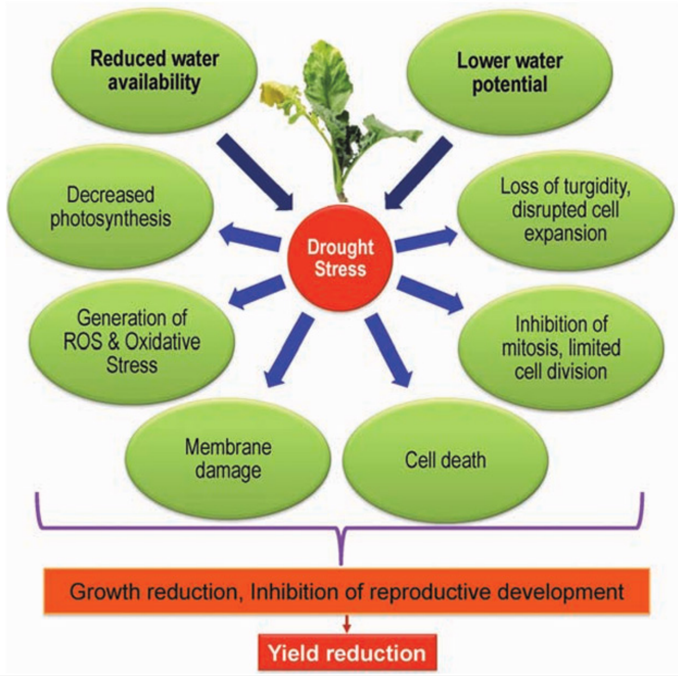

Figure 1: *Showing the major cellular damages at the onset of water stress conditions (Hasanuzzaman et al., 2013).*

Biochemical responses to water stressed regimes

Drought stress regimes have an impact on a variety of physiologic activities and redox balance. Similar to bio-chemicals, DNA and cellular protein content as well as membrane lipo-proteins degrade in water-limited environments (Khan *et al*., 2021). Plants produce a number of chemical, physical, and molecular defense systems against drought stress regimes; by accumulating certain osmolytes such as glycine betaine, proteins, proline and carbohydrates; thus, maintaining redox potential and promoting proline biosynthesis, salicylic acid application increased tolerance to drought-stress (Sytar *et al*., 2019). Under low water availability, compatible solutes are accumulated chiefly in the cytoplasm and scavenge ROS, enhancing thus protecting biomolecules from oxidation (Ghafar *et al*., 2021). Under drought, cells of plants gather solvable ingredients and condense their cytoplasm. The growth of enzymes and the entire photosynthetic process may be hampered in certain circumstances by the concentration of these unusual compounds (Mahmood *et al*., 2021). The rapid decline in photosynthesis leads to a decrease in the amount of ribulose-bisphosphate regeneration, the maximum rate of ribulose-carboxylate, NADP-malate enzymes and other essential enzymes like kinase pyruvate (Wu *et al*., 2021). In order to meet the demands of reduced NADPH, ATP producing, and ROS making, noncyclic electron transport was also diminished. Dissimilar varieties may react to and acclimatize to drought differently (Abhinandan *et al.*, 2018).

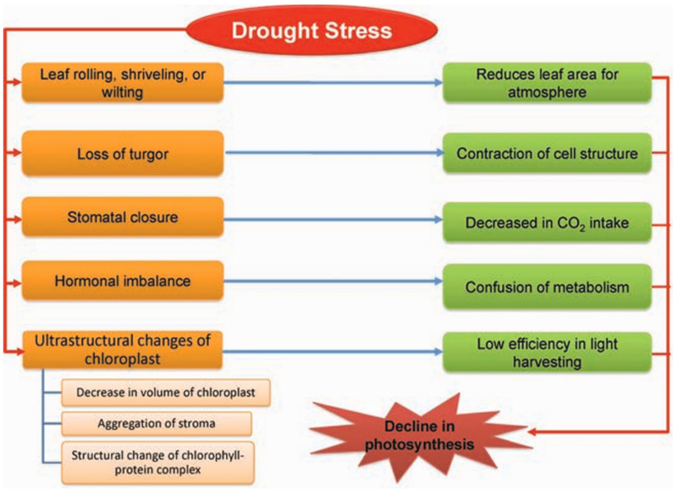

Figure 2: *Representing the underlying factors involved in photosynthesis decline and total biomass reduction under drought regimes (Hasanuzzaman et al., 2013).*

Formation of reactive oxygen species (ROS) under drought

The main obstacle to sustainable agriculture is water scarcity and soil salinity (Talbi *et al.*, 2020). In a climate under stress from drought, ROS production coexists with a typical metabolic process, such as aerobic metabolism (Hu *et al.*, 2018). Increased ROS generation in drought-stressed conditions is inevitable; dangerous phytotoxic levels of ROS can cause cellular damage and expiry of plant. At low concentrations, they perform as a crucial signaling molecule, activating a variety of stress-response mechanism (Franchina *et al.*, 2018).

Regulation of antioxidant compounds and osmotic adjustment under drought stress

Previous research has shown that under drought stress circumstances, phenolic content increased by 100% (Ali *et al.*, 2020). In comparison to well-watered tomatoes, tomatoes under drought stress contained greater total phenolic (Hura *et al.*, 2007). The tomato fruit's high phenolic content shields the tissues from the damage of oxidation (Ali *et al.*, 2020). In spite of all adverse circumstances, high leaf antioxidant levels were noted. Enzymes that preserve membrane structure and alter osmotic potential through signaling systems that control the expression and transcription of genes could scavenge chemically reactive oxygen species (Bhardwaj *et al.*, 2021). The authors state that the study's ultimate goal was to determine the quantity of antioxidant compounds found in the fruit of tomato which received enough watering or underwent through drought for 10 days. The study found that limited water in the soil enhanced GPX levels in seedlings of rice, therefore, it was suggested that this was a useful screening method for tolerance traits (Ahanger *et al.*, 2021). Similar to this, cultivars of wheat with raised levels of proline content in the leaf tissues effectively used the available water. In reply to several abiotic stressors, proline accumulated more dramatically (Al-Ghzawi *et al.*, 2018). It is well known that drought resistance is correlated with greater concentrations of proline in various crops grown under low water levels. In comparison with cultivars that are more vulnerable to dryness, these drought-tolerant types have more proline (Khan *et al.*, 2019), (Figure 3).

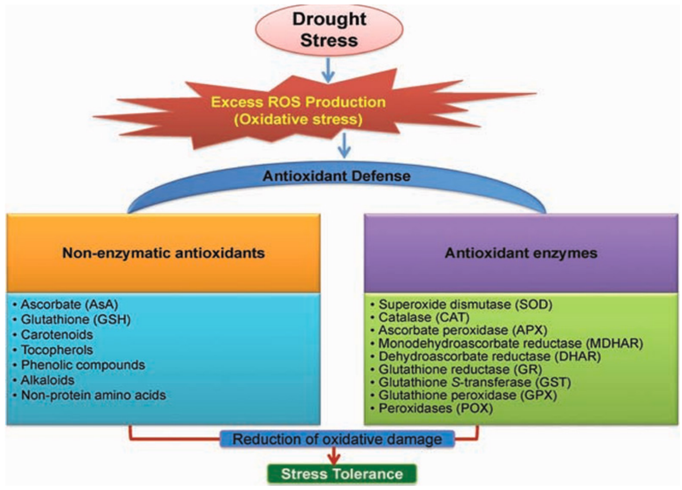

Figure 3: *Depicting the antioxidant and non-antioxidant natural defense responses of plants subjected to drought stress (Hasanuzzaman et al., 2013).*

Conclusions and Recommendations

A major environmental stressor that poses a danger to crop productivity globally is drought. However, drought stress causes more harm during grain-filling and reproductive stages. Based on the stage of crop, intensity and duration of drought period grain yield is affected differently. Crop management techniques that are associated with drought resistance can help lessen the undesirable results of drought. Understanding the effects of terminal water stress in depth is necessary to increase drought resilience. Due to the decreased stomatal conductance caused by drought stress, CO_2 absorption rates are impacted over the long run. Reduced gaseous exchange and deteriorated photosynthetic pigments lead to reduced plant growth and productivity. Forked root systems ability to capture and hold more water from the soil and transfer it to above plant parts for various physiological functions has been linked to drought resistance and high biomass output.

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Novelty Statement

The present work is Novel and encompasses a wide range of data collected from recent published literature which has never been gathered before on national level in the form of a comprehensive literature review in this specific subject area.

Author's Contribution

Wadood Shah: Conceptualization, writing original draft and editing.
Sanam Zarif Satti: Formal analysis and visualization.

Conflict of interest
The authors have declared no conflict of interest.

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