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*Review Article*

# REPERCUSSIONS OF WATERLOGGING STRESS AT MORPHO-PHYSIOLOGICAL LEVEL ON COTTON AND WAYS TO LESSEN THE DAMAGE TO CROP YIELDS

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***Abstract***: *The volatility of the climate, which is characterized by intermittent heavy rainfall, causes flooding. The problem is exacerbated in soils with limited internal drainage by warm weather patterns. Cotton is commonly grown under these conditions, putting it at risk for yield losses due to summer flooding following heavy rainfall. This requires a deeper understanding of cotton's processes for waterlogging tolerance. This research analyses likely reasons of waterlogging-induced yield loss in cotton, as well as ways for boosting waterlogging tolerance, based on the little information available on cotton and recommendations from other species. The yield penalty is impacted by soil type, phenological stage, and the total time roots were exposed to less than 10% air-filled porosity. In addition to other soil-related issues, an oxygen deficiency in the root zone alters the redox state of nutrients, rendering some inaccessible (such as nitrogen) or potentially poisonous to plants. In addition, xylem-transported root hormones have long been linked to oxygen shortage. Reduced root growth, reduced nutrient uptake and transport, and disturbed hormone signaling are examples of subterranean effects on shoots that impact canopy formation, photosynthesis, and radiation utilization efficiency. Cotton has no evident root aerenchyma reaction and low fermentative activity compared to cereals with greater waterlogging tolerance. We believe that these traits have a significant effect on cotton's susceptibility to prolonged waterlogging. These subsurface components' effects on photosynthesis, shoot functionality, and yield components are discussed. Utilizing management techniques such as fertilizer application, soil aeration, and controlled watering helps prevent waterlogging. Reducing the expression of the genes directing ethylene production and introducing anti-ethylene compounds to limit ethylene biosynthesis are effective methods for preventing yield losses in cotton plants that have become waterlogged.*

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## Introduction

Waterlogging is a global problem that affects the distribution of plant species and crop productivity. According to FAO study, 20-30 million hectares of irrigated land have been damaged by soil waterlogging due to insufficient soil drainage, intense irrigation, and changeable weather. This has an international effect on crop yields. Significantly lower oxygen ($O_2$) diffusion rates are observed in saturated soils. When microbial and plant root respiration drain $O_2$ at the same time, soil $O_2$ levels rapidly drop below the threshold (Najeeb, Bange, et al., 2015). High temperatures, which increase respiratory activity, make this surgery more difficult. Even when the soil is completely saturated with water and its air-filled porosity is less than 10%, these levels can be critical for roots, limiting respiration rates below the level required for maximal energy production (Christianson et al., 2010).

## Morphological alterations

### Root development and growth

Even in crops that are heavily fertilized and irrigated, continual root extension is necessary for resource acquisition during vegetative growth. Waterlogging and other environmental conditions that inhibit root development are crucial for optimizing crop yield (Zhang et al., 2016).

According to laboratory research, for optimal root production and growth, root apices must be at or above the COP. The COPs of various plant species differ. The COP for respiration (COPR), which is determined by the characteristics of tissues through which $O_2$ must flow (such as the fraction of stele) and the $O_2$ affinity of oxidizes, determines the $O_2$ concentration below which root extension begins to decrease. Root development in cotton grown in the field is dependent on moderately hypoxic (10% $O_2$) soil oxygen levels, which restrict microbial growth (Zhang et al., 2015). Due to a shortage of oxygen, cotton plants were unable to spread their tap roots for two to three minutes, but as the oxygen level was restored, the process continued. Conversely, three hours of anoxia was sufficient to kill the root tips of cotton plants. Cotton roots should respond quickly to low oxygen levels (Najeeb, Atwell, et al., 2015).

In addition to other biotic and abiotic soil variables, the distribution and availability of gases and nutrients in waterlogged soil have a considerable effect on the morphological and functional characteristics of roots (Milroy & Bange, 2013). When the shoot-root continuum is present, the soil media, intercellular gas gaps, and aerenchyma are the primary pathways for $O_2$ supply to roots. In wet or low-oxygen soils, the principal source of $O_2$ delivery to the roots of flood-tolerant plants is the shoots and their connection to the atmosphere. Depending on criteria such as cortical cell shape and arrangement, route lengths, cellular $O_2$ demands and radial losses, stele vs. cortex radius, and root apical morphology, roots only receive a part of the oxygen required for typical aerobic activity. Even if the outer cortical tissues of a single root axis are aerobic, the apices and stele may be anaerobic (Liu et al., 2015). Although it is unknown what causes tissue-specific variations in $O_2$ status in less tolerant dicotyledonous plants, such as cotton, phenotypic variability in radial diameters and root biophysical characteristics can be utilized (Dodd et al., 2013; Kuai et al., 2016).

**Consumption of nutrients**

Cotton and other irrigated crops require inorganic fertilizers to thrive. A drop in soil oxygen levels following heavy rain begins a number of chemical processes. As water logging develops, soils become anoxic and redox potentials steadily increase to the point where ions become toxic or inaccessible (Guo et al., 2010). To prevent root damage, these solutes must be excluded, sequestered, or deoxidized. The development of these regulatory systems relies heavily on rhizosphere $O_2$ concentrations, which is improbable in non-aerenchymatous cotton roots until the bulk soil begins to re-aerate (Wu et al., 2012). During and during times of water logging, when atmospheric $O_2$ supply is significantly depleted, cotton's root energy status to maintain active transport systems and membrane integrity becomes critical. There is evidence to suggest that integrating these adaptive systems can prevent Mn poisoning after eight days of flooding. Because reactive oxygen species impair metabolic function, reaeration following water logging introduces new hurdles for roots. However, loss of oxygen is not the main cause of root tissue degeneration, especially around the apices (U Najeeb et al., 2016).

**Cotton production and yield**

Cotton's vegetative growth and yield are influenced by the length of time the root system is exposed to low soil oxygen concentrations (10% $O_2$), the type of soil, and the growth stage. According to prior studies, a length of four to thirty-two hours of flooding significantly lowered cotton lint yield(Jiang et al., 2013). Cotton yield was unaffected by 72 hours of waterlogging, indicating that plant sensitivity to waterlogging varied widely depending on experimental conditions. In recent years, the creation of relatively waterlogging-tolerant cotton cultivars, the improvement of agronomic practices, the reduction of soil compaction (as a result of continuous waterlogging), and the implementation of sophisticated land leveling technology have all contributed to increased crop yield. Field research has also revealed that yield losses in waterlogged cotton are inversely proportional to the height of the ridges; eliminating the ridges increased yield under aerobic conditions but exacerbated waterlogging damage (Bange et al., 2010).

**Various modifications at physiological level**

**Photosynthesis**

Depending on the species, flooding and subsequent soil saturation frequently cause a significant decline in photosynthetic rate, which can drop by 10 to 90%. There are a number of ways that hypoxia might impact photosynthetic activity, according to scientific research (Wen-qi et al., 2010). The vulnerability of cotton to water logging is related to photosynthetic inhibition. Water logging treatments for 72 hours significantly reduced cotton photosynthesis, but as soil oxygen levels rose, photosynthesis returned to normal. Later in growth, the rate of photosynthesis evolved and became less susceptible to soil oxygen levels. Cotton leaves' nutritional insufficiency has been primarily blamed for the fall in leaf photosynthetic rates. Cotton that had been wet had minimal impact from foliar and soil fertilizers (N, P, and K). This study suggests that reduced leaf function may be explained by long-distance signalling from the roots, including hydraulics (like stomata closure) and hormones (Ullah Najeeb et al., 2016b).

***Effects at the cellular level***

The oxygen content drops to 20.9% when there is standing water, which causes hypoxia. Depending on elements like temperature, soil, the amount of organic matter, and microbial activity, the partial pressure of oxygen may decrease from 20.9 to 1 kPa after a day of flooding. ATP oxidative phosphorylation in the mitochondria is necessary for the maintenance and function of an organ or tissue (Yang et al., 2012). The rate at which cells use ATP determines how much oxygen is used. Therefore, oxygen loss in wet or submerged conditions has immediate and severe effects on cell physiology (Li et al., 2013). Functions that require ATP, such DNA replication and cell division, are slowed down to get through this energy crisis. The anaerobic synthesis of ATP from glycolysis and the fermentation of pyruvate to ethanol (catalysed by PDC, ADH) or lactate (catalysed by LDH), both of which create $NAD^+$, are the two primary mechanisms that maintain anaerobic carbon metabolism. Some plants, like maize, undergo a sharp rise in cytosolic Ca2+

when there is not enough oxygen. Hypoxia-responsive genes' expression is changed as a result. Examples of acclimation responses include regulating the concentrations of metabolites including fructose, pyruvate, and sucrose as well as increasing alanine, -aminobutyric acid (GABA), succinate, and occasionally malate. Fructose 6-phosphate 1-phosphotransferase (PFP) is used in place of phosphofructokinase to produce fructose-1-6-bis-P (PFK). An enzyme called pyruvate phosphate dikinase (PPDK) transforms pyruvate into phosphate (PK). In place of invertase, sucrose is broken down by the enzyme UDP-dependent sucrose synthase (SUS), and PPi-dependent enzymes are more effective than ATP-dependent ones. ROS are produced by hypoxia, and ROS-mediated signaling supports a range of immune responses, programmed cell death, and plant growth, including the growth of the rice and wheat plants (Long et al., 2015). In the internodes of rice stems, $H_2O_2$ encourages the development of adventitious roots and lysigenous aerenchyma. Cotton plant survival in low-oxygen conditions is aided by cotton mitochondrial ROS, which activate the mitogen-activated protein kinase MAPK6. SOD, CAT, APX, POD, GPX, and MDHAR are a few examples of the enzymes that assist stop oxidative cell damage (Yang et al., 2012). Oxidative damage occurs to proteins, lipids, and nucleic acids when they are oxidized. On the other side, an excess of ROS can harm cells through oxidation. Plants skillfully control ROS defense and signalling cascades to maintain a healthy balance between survival and stress tolerance. The amount of energy required for a cell to maintain anaerobic metabolism, pH homeostasis, and ROS detoxification determines how long it can survive without oxygen (Qin et al., 2012).

**Pathways of signalling and control of genes**

As a result of proteomic and genetic techniques, we now have a better grasp of how the body responds to oxygen deprivation, but we still do not fully understand the entire series of events that results in water logging tolerance (Ullah et al., 2016a). Numerous microarray studies have demonstrated that hypoxia alters the expression of genes involved in signal transduction. There are probably many different organisms that can use rice coleoptile sugar signalling in low-oxygen situations. Additionally, it is frequently reported that hypoxia-induced gene expression responses include nitrogen metabolism, cell wall disintegration, and ethylene production. It has been shown that similar genes across a wide spectrum of flood tolerance in a variety of plant species are activated when there is a lack of oxygen. These repeated changes show that early bacteria created "solutions" to deal with the most adverse environmental circumstances (Lee et al., 2014).

**Conclusion**

According to this review, waterlogging effects the morphological, physiological, and transcriptional responses of several plant features to stress. It is essential to comprehend the multiple metabolic alterations, structural reorganisations, and gene activity that may increase the likelihood of promoting plant growth and development under these intense stress conditions. The most efficient component is the creation of a system to battle $O_2$ depletion and scarcity. Redox homeostasis, as well as ROS signalling and scavenging, is crucial during hypoxia produced by water logging or submersion. Recognizing and overcoming these obstacles helps increase crop yield. Targeting organelle and plasma membrane transporters may aid in the recovery of $O_2$ permeability, ionic equilibrium, and cellular metabolites produced by an excess of water. By selecting morphological characteristics that are resistant to waterlogging and submersion stress and constitutively expressing these traits in propagating lines, we can concentrate genetic change to generate varieties that can survive or endure these challenges. By identifying and characterizing the genes that respond to water logging and submersion, as well as their upstream and downstream signalling cascades, it may one day be possible to build stress-resistant organisms.

**Conflict of interest**

The authors declared absence of conflict of interest.

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