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Comprehensive Assessment of Drought Stress on Morphometric and Molecular Parameters of *Triticum Aestivum* L.

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Abstract.

Drought stress is one of the most significant environmental factors limiting wheat productivity under current climate change conditions. Increasing temperatures, irregular precipitation, and growing water scarcity intensify the impact of drought on agricultural ecosystems and threaten global food security. This review provides a comprehensive analysis of the morphometric, physiological, and molecular responses of *Triticum aestivum* L. to water deficit based on published scientific studies. The analysis shows that drought stress causes significant changes in plant morphology, including reduced shoot growth, decreased leaf area, and modifications of root architecture that enhance water uptake. At the physiological level, drought leads to reduced photosynthetic activity, decreased relative water content, accumulation of osmoprotective compounds, and activation of antioxidant defense systems. At the molecular level, stress responses are regulated by complex gene networks involving transcription factors such as DREB and NAC, as well as drought-responsive proteins including LEA proteins. The integration of morphological, physiological, and molecular indicators provides a comprehensive framework for evaluating drought tolerance in wheat and contributes to the development of drought-resistant cultivars capable of maintaining productivity under water-limited conditions.

Keywords:

Triticum aestivum L.
drought stress
morphometric parameters
physiological responses
molecular mechanisms
drought tolerance

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Introduction

In recent decades, global climate change and increasing anthropogenic pressure on natural ecosystems have significantly altered environmental conditions worldwide. Rising temperatures, irregular precipitation patterns, and the growing frequency of drought events contribute to increasing water scarcity in many agricultural regions. These environmental changes are further intensified by human activities such as intensive land use, industrial emissions, and unsustainable water management practices. As a result, the ecological stability of agroecosystems is gradually deteriorating, which poses serious risks to global food security. Under these conditions, understanding the mechanisms of plant adaptation to drought stress becomes essential for ensuring sustainable agricultural production and maintaining the availability of food resources for the growing human population [1; 6; 8; 9; 11–15; 19].

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops globally and serves as a major source of calories and protein for human populations. However, increasing climate variability and irregular precipitation patterns have intensified the frequency and severity of drought episodes in many wheat-growing regions. As a result, drought stress has emerged as a major environmental constraint, significantly reducing crop productivity and threatening food security [16; 21].

Water deficit disrupts plant metabolism at multiple organizational levels. Reduced soil moisture affects cellular hydration, limits nutrient uptake, and alters photosynthetic processes. Consequently, drought stress influences the morphology, physiology, and biochemical composition of wheat plants, ultimately affecting grain formation and yield stability [17].

Plant responses to drought involve complex adaptive mechanisms that enable survival under water-limited conditions. These mechanisms include morphological modifications such as deeper root systems, physiological adjustments such as stomatal regulation and osmotic balance, and molecular responses involving the activation of stress-related genes [4].

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Because drought tolerance is a polygenic trait influenced by numerous environmental factors, comprehensive evaluation requires integrating morphometric traits with molecular indicators. Such an integrative approach allows researchers to identify drought-resistant genotypes and develop improved breeding strategies aimed at enhancing wheat resilience under climate stress.

The objective of this study is to provide a comprehensive assessment of drought-induced changes in wheat by analyzing both morphometric and molecular parameters reported in contemporary scientific literature.

Materials and Methods

This study is based on a systematic analysis of peer-reviewed scientific publications focusing on drought stress responses in bread wheat. Articles published in international journals were selected according to the following criteria: relevance to drought stress in *Triticum aestivum* L., inclusion of morphometric or physiological measurements, analysis of biochemical or molecular mechanisms of stress response. The selected studies were analyzed comparatively to identify consistent patterns in morphological, physiological, and genetic responses to water deficit.

Results and Discussion

Analysis of multiple studies demonstrates that drought stress significantly alters plant morphology and growth dynamics in wheat. Farooq et al. [5] reported that water deficit reduces plant height, leaf area, and biomass accumulation due to limitations in cell expansion and photosynthetic activity. These morphological changes represent one of the earliest visible responses to drought conditions.

Several researchers emphasize the adaptive significance of root system modification. Blum [3] showed that drought-tolerant wheat genotypes often develop deeper and more extensive root systems, allowing them to access water from deeper soil layers. This trait has been widely recognized as a key morphological indicator of drought resistance.

Comparative studies indicate that drought stress frequently results in a reduction of shoot growth while simultaneously stimulating root elongation. Such changes lead

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to an increased root-shoot ratio, which enhances the plant's ability to maintain water uptake during prolonged dry periods.

Reproductive structures are particularly sensitive to drought conditions. Barnabas et al. [2] demonstrated that drought during the flowering and grain filling stages significantly reduces spike fertility, grain number, and grain weight. These findings explain the substantial yield losses commonly observed under drought stress.

Physiological responses play a crucial role in plant adaptation to water deficit. One of the most commonly used indicators of drought stress is relative water content (RWC), which reflects the hydration status of plant tissues. Several studies report that RWC decreases significantly under drought conditions, indicating reduced cellular water availability.

Drought stress also disrupts photosynthetic processes. According to Lawlor and Cornic [10], stomatal closure reduces CO₂ diffusion into leaf tissues, leading to decreased photosynthetic rates. This effect is further amplified by the degradation of photosynthetic pigments and structural damage to chloroplast membranes.

Another important physiological response is the accumulation of osmoprotectants, such as proline and soluble sugars. These compounds help stabilize cellular structures, maintain osmotic balance, and protect enzymes during dehydration. Hasanuzzaman et al. [7] demonstrated that proline accumulation may increase several times in wheat plants exposed to drought stress.

Oxidative stress is another consequence of drought conditions. Water deficit often leads to increased production of reactive oxygen species (ROS), which can damage cellular components. To counteract this effect, plants activate antioxidant defense systems involving enzymes such as superoxide dismutase, catalase, and peroxidase.

At the molecular level, drought stress activates complex gene regulatory networks. Shinozaki and Yamaguchi-Shinozaki [20] showed that transcription factors play a central role in regulating plant responses to dehydration.

Among the most important regulators are DREB transcription factors, which activate stress-responsive genes associated with osmotic adjustment and cellular protection.

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Similarly, NAC transcription factors control gene networks related to stress signaling and developmental regulation.

Another group of genes involved in drought tolerance encodes LEA (Late Embryogenesis Abundant) proteins, which protect cellular structures from dehydration damage. These proteins help maintain membrane integrity and stabilize proteins under water deficit conditions.

Hormonal regulation also plays an important role in drought responses. Abscissic acid (ABA) acts as a key signaling molecule that triggers stomatal closure and activates stress-responsive gene expression. According to Peleg and Blumwald [18], ABA-mediated signaling pathways are essential for coordinating physiological and molecular responses to drought stress.

Conclusion

Drought stress is one of the major environmental factors limiting wheat productivity worldwide. Analysis of numerous studies shows that water deficit affects wheat plants at multiple biological levels, including morphological, physiological, and molecular processes. Structural changes such as reduced shoot growth and enhanced root development are accompanied by physiological responses including decreased photosynthetic activity, osmotic adjustment, and activation of antioxidant defense systems. At the molecular level, drought tolerance is regulated by complex gene networks involving transcription factors and stress-responsive proteins coordinated by hormonal signaling pathways. Understanding these integrated mechanisms provides a scientific basis for identifying drought-tolerant genotypes and developing wheat varieties capable of maintaining productivity under water-limited conditions.

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