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Editorial

Adaptive Mechanisms of Tree Seedlings to Adapt to Stress

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As the most critical stage in the plant life cycle, the seedling period assumes a crucial role in forest community succession and vegetation restoration. Seedlings are susceptible to both biotic and abiotic stresses during their growth. Ongoing climate change is amplifying the frequency and severity of stresses such as drought, flooding, extreme temperatures, and pest infestations. Over the long-term evolutionary process, tree seedlings have developed a suite of adaptive mechanisms to cope with these stresses. Investigating seedling growth mechanisms is instrumental in comprehending and elucidating the ecological adaptation characteristics that ensure enhanced growth and performance in natural settings.

For this Special Issue, we welcome all research endeavors addressing the adaptation mechanisms of tree seedlings to biotic and abiotic stresses, emphasizing their pivotal roles in mitigating stresses within forest ecosystems. Thus, this Special Issue, titled "Adaptive Mechanisms of Tree Seedlings to Stress", aims to compile contemporary research findings on the various adaptive mechanisms of tree seedlings to stressors, including light conditions, intraspecific and interspecific competition, extreme climate events, microplastic pollution, and heavy metal contamination.

Herein, we will briefly outline the contributions of the fifteen papers (fourteen research papers and one review paper) published in this Special Issue in the subsequent sections.

1. Adaptation to Light Stress

Light stress is a critical factor in the life history of plants. Adaptation to varying light environments is pivotal to understanding tree mechanisms under light stress. Li et al. [1] investigated the physiological and morphological leaf plasticity of *Phoebe bournei* at different ontogenetic stages, from seedlings to saplings, in response to light stress. Their findings revealed an increase in the nonphotochemical quenching of leaves with plant age, suggesting enhanced photoprotective capacity with ontogeny. This underscores the increasing leaf plasticity in juvenile *P. bournei* when adapting to changing light resources.

In another study, Xue et al. [2] examined the effects of four levels of manipulated light intensity (0%, 40%, 60%, and 80%) on the seedling emergence and early growth of *Castanopsis hystrix*, a dominant tree species with a high natural regeneration capacity in southern subtropical China. Through various physiological and biochemical measurements, their results indicated that 60% light intensity promoted maximum growth and the photosynthetic characteristics of *C. hystrix* seedlings.

Liquidambar formosana Hance, a common deciduous broad-leaved tree known for its rapid growth and adaptability, was also investigated as a target tree species regarding seedling emergence and early growth under different light intensity levels [3]. Their controlled experiment involved three light-intensity treatments (20%, 60%, and 100% of full sunlight). The results demonstrated significant increases in seedling height, stem diameter, and root length with increased light intensity, with the maximum total, root, stem, and leaf biomasses observed at 100% light intensity. These findings may elucidate the challenges faced by *L. formosana* seedlings in establishing under canopy conditions with poor light availability.

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Thinning, a common practice in plantation management, often induces light stress and alters microbial activities. Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook), a main afforestation species in China known for its fast growth and high productivity, faces challenges due to soil phosphorus depletion. Ma et al. [4] employed metagenomic sequencing to investigate the relationship between different thinning intensities and phosphorus cycling-related microbial genes in *C. lanceolata* plantations. Their findings identified Acidobacteria (47.6%–53.5%) and Proteobacteria (17.9%–19.1%) as the primary contributors to functional phosphorus cycling genes. Moreover, appropriate thinning intensities were found to increase soil phosphorus availability by suppressing the microbe-mediated mineralization of organic phosphorus and solubilization of inorganic phosphorus.

2. Adaptation to Salt Stress

Soil salinization currently affects approximately 20% of the world's soil, with projections indicating an escalation under climate change. Consequently, salinity stress has emerged as a significant abiotic factor impacting seedlings.

Alternative splicing (AS) serves as a critical mode of gene expression regulation, which is widely implicated in both plant growth and adversity resistance. Using the PromethION platform, Wang et al. [5] investigated the impact of different salt stress levels on the full-length transcript sequencing of leaves from *Salix matsudana* Koidz 9901, a highly salt-tolerant willow species that is extensively cultivated in saline–alkali lands. Their findings revealed an increase in genes in AS sites during salt treatment. A comparative analysis of differentially expressed genes and differentially alternatively spliced genes during salt stress unveiled distinct mechanisms of gene expression regulation in response to salt stress.

Htet et al. [6] explored the role of 24-epibrassinolide (EBR) in regulating the growth and physiological performance of *Melia azedarach* seedlings from two different seed sources under varying salt stress levels over a 60-day experimental period. Their main finding indicated that the appropriate application of EBR enhanced seedling stress tolerance by promoting growth and physiological systems. Moreover, the superior performance observed in Shenyang seedlings under the EBR treatment concentration suggested coastal natural origins, with greater adaptation observed in *M.azedarach*.

Heterogeneous nutrient patches can induce morphological and physiological changes in seedlings under nutrient stress. Li et al. [7] investigated differences in *Fokienia hodginsii* seedling growth and root vitality under various heterogeneous nutrient environments by manipulating gradients of nitrogen (N), phosphorus (P), and potassium (K) nutrients. Their key findings revealed that *F. hodginsii* seedling height was the greatest in N heterogeneous environments, whereas root biomass was highest in P heterogeneous environments. Additionally, root catalase, superoxide dismutase, and peroxidase activities were highest in the P heterogeneous environment, while the highest average malondialdehyde (MDA) content was found in the K heterogeneous environment. These results suggest the low tolerance of *F. hodginsii* to the K heterogeneous environment, providing insights for *F. hodginsii* management.

Furthermore, heterogeneous nutrient patches were found to be correlated with water stress. Yang et al. [8] reviewed the adaptive strategies employed by clonal plants in heterogeneous water stress, drawing on the theoretical basis of phenotypic plasticity and physiological integration. Phenotypic plasticity adaptation was manifested in reproduction and population stability through the regulation of individual size, allocation of population biomass, and number of daughter plants. Physiological integration adaptation was observed through the clonal translocation of communicated substances and resources, such as water, mineral nutrition, photosynthetic products, and secondary metabolites.

3. Adaptation to Natural Physiological Stressors

Natural physiological stressors also significantly influence the adaptive mechanisms of trees, including leaf damage [9], life stages [10], seasonal cycles [11], and altitude gradients [12].

The compensatory capabilities of trees following leaf damage play vital roles in plantation management. Su et al. [9] investigated the effects of leaf damage on the growth, anatomical, and physiological characteristics of *Populus talassica* × *Populus euphratica*. Artificial defoliation treatments were applied to simulate leaf damage at four levels: 0%, 25%, 50%, and 75% leaf removal. Key findings revealed that moderate treatments (25% and 50% leaf removal) significantly enhanced growth parameters, such as leaf length, leaf area, and specific leaf area, while the 75% leaf removal treatment significantly decreased most growth parameters. Additionally, photosynthetic compensation was observed under 50% leaf removal, with the stomatal width, area, opening, and net photosynthetic rate significantly increasing. This study suggests that keeping leaf damage levels within 50% can enhance the growth of *P. talassica* × *P. euphratica*.

Seedling renewal is influenced by the growth years of seedlings. In [10], the response of Chinese cork oak (*Quercus variabilis*) root endophyte communities to different growth years was investigated. Changes in the composition of root bacterial communities of *Q. variabilis* seedlings after one, two, and three years of growth were studied. The main finding demonstrated that the growth year serves as a decisive factor for the differences found in root endophytic bacterial communities. Although the structure and function of bacterial communities changed with an increase in the growth years of *Q. variabilis* from field samples, the study suggests that further research employing pure culture and pot experiments is warranted.

Understanding the adaptation of evergreen tree species, including pine, to low winter temperatures is crucial. Yue et al. [11] investigated changes in physiological state, photosynthetic function, and material metabolism in needles of *Pinus densiflora* during the overwintering and spring recovery stages. Despite the obvious characteristics of freezing injury after experiencing sub-zero temperatures in winter, needles of *P. densiflora* still exhibited weak photosynthesis at temperatures above zero. The results indicate that *P. densiflora* needles do not improve frost resistance through osmotic adjustment but increase carotenoid content, soluble sugar, and protein contents during the overwintering and spring recovery stages.

Elevation alters environmental conditions, impacting soil microbiological activities. Microbial residue carbon plays a significant role in soil carbon formation, affecting tree growth. Sun et al. [12] investigated amino sugars as biomarkers for microbial residue carbon in organic and mineral layers across different elevation gradients in the Wuyi Mountains. The results showed that more residue carbon content derived from fungi than bacteria in soil, with the ratio of fungal residue carbon to bacterial residue carbon decreasing from the organic layer to the mineral layer. Redundancy analysis indicated that elevation explains a substantial proportion of the variations in microbial residue carbon accumulation in both organic and mineral layers.

4. Application of Seedling Adaption to Stresses

Effective human interventions can significantly enhance the adaptation of trees to multiple stresses. Papers in this Special Issue also focus on ways to improve the growth capacity of seedlings [13–15].

As a level II priority protected wild plant in China with high commercial value, the habitat adaptability of *Toona ciliata* var. *pubescens* is declining due to overexploitation and its poor natural regeneration capacity. Jiang et al. [13] investigated the effectiveness of inoculating *T. ciliata* var. *pubescens* seedlings with *Septoglomus viscosum* on growth, using RNA-Seq analysis to compare gene expression differences between arbuscular mycorrhizal fungus (AMF)-inoculated and non-mycorrhizal treatments. The results indicated that AMF inoculation activated genes involved in nutrient uptake, stress responses, signal transduction, and substance transportation, potentially promoting seedling growth by enhancing root cell growth.

Che et al. [14] studied the growth of *Quercus variabilis* variabilis seedlings in different substrates with varying ratios of cork flour using high-throughput sequencing and qPCR methods. Their results highlighted that adding cork flour significantly increased root and shoot weight, rhizosphere bacterial richness, and the abundance of nitrogen and phosphorus metabolism-promoting microbial taxa in seedlings.

Cao et al. [15] investigated the effects of heavy metals on growth, physiological traits, tolerances, and accumulation characteristics in 2-year-old saplings of *Ligustrum obtusifolium*, known as a trace element root-hoarding plant. They conducted a pot experiment with gradient levels of trace element concentration. The results showed a significant decrease in chlorophyll content (Chl-a, Chl-b, and total Chls) with increasing trace element levels. A 10% decrease in the biomass of *L. obtusifolium* was observed as a reference index, with threshold values of 300 mg/kg for Cr, 400 mg/kg for Pb, and 300 mg/kg for Zn identified. By comparing antioxidant enzyme activity and transfer ability, *L. obtusifolium* was found to be particularly suitable for the phytoremediation of Cr pollution in western China.

5. Conclusions

As Guest Editors, we strongly believe that this Special Issue represents a valuable compilation of studies focusing on seedling adaptation to diverse biotic and abiotic stresses. The collected papers serve to advance our understanding of the mechanisms underlying seedling responses to multiple stressors. Importantly, they provide a scientific basis for applying adaptation strategies in forest management practices. Ultimately, our hope is that this collection of studies will facilitate the development of more effective strategies for promoting the health and resilience of forest ecosystems in the face of ongoing environmental challenges.

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