

Perspective

Plant adaptations to climate extremes: Lessons from native species

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Climate extremes such as droughts, heatwaves, floods, cold snaps, and salinity stress represent some of the most significant threats to plant survival and ecosystem stability in the Anthropocene. Global climate change is intensifying the frequency, duration, and severity of these events, challenging agricultural productivity, food security, and biodiversity conservation. Native plant species, however, provide valuable insights into the strategies plants use to adapt and persist under extreme conditions. Through morphological, physiological, biochemical, genetic, and phenological adaptations, native species have evolved resilience to fluctuating and sometimes hostile environments. Their survival strategies include deep or specialized root systems, water storage tissues, protective structures like thick cuticles or trichomes, stomatal regulation, osmotic adjustment, synthesis of stress proteins and secondary metabolites, and shifts in flowering or seed dormancy patterns. Studying these adaptations not only enhances our understanding of evolutionary processes but also offers lessons for crop breeding, ecosystem restoration, and climate-resilient land management. This article explores the wide spectrum of plant adaptations to climate extremes, highlights case studies of native species from diverse ecosystems, evaluates their ecological and agricultural significance, and underscores the necessity of integrating these lessons into strategies for global sustainability.

Keywords: Plant adaptations, Climate extremes, Native species, Drought resistance, Heat tolerance, Salinity adaptation, Flood resilience, Phenological plasticity, Biodiversity conservation, Climate change resilience.

Introduction

Plants, as sessile organisms, cannot escape adverse environmental conditions and must therefore develop mechanisms to cope with extreme climatic stressors. With the increasing unpredictability of weather patterns under global climate change, plants face mounting challenges that threaten their survival, distribution, and reproductive success. Extreme events such as prolonged droughts, excessive heat, flooding, frost, or soil salinity impose physiological and biochemical stress, disrupting photosynthesis, growth, and productivity. While many cultivated species suffer yield losses under such conditions, native plants—those that have evolved in specific ecological niches over millennia—often display remarkable resilience. Native species embody evolutionary experiments in survival, shaped by natural selection in environments characterized by variability and extremes. Their adaptive traits provide both ecological stability in their native habitats and inspiration for developing climate-resilient agricultural and ecological systems (DalCorso G, et al. 2013). Exploring the strategies of native species offers critical insights into how plants can survive in hostile environments and how human societies can harness this knowledge to adapt agriculture and ecosystem management in an era of rapid climate change.

Description

Adaptations of plants to climate extremes manifest across multiple dimensions. Morphological adaptations are often the first line of defense against environmental stress. In drought-prone environments, for example, native plants frequently exhibit deep root systems that tap into groundwater reserves, or widespread shallow roots that quickly absorb surface moisture after brief rains. waxy cuticles, hairy leaf surfaces, and reduced leaf sizes minimize transpiration. Similarly, plants in saline environments like mangroves develop pneumatophores—specialized aerial roots that allow gas exchange in waterlogged, oxygen-poor soils—while accumulating salt in vacuoles or excreting it through salt glands on their leaves (Sharma RK, et al. 2005). Plants in flood-prone areas adapt by developing aerenchyma tissues, which facilitate oxygen transport to submerged roots, or by elongating stems rapidly to escape rising water levels. Cold-tolerant plants may reduce leaf size, form rosettes close to the ground to reduce exposure, or develop insulating trichomes to protect against frost damage.

Physiological and biochemical adaptations complement morphological traits. Stomatal regulation is one of the most crucial mechanisms plants use to cope with extremes, allowing them to balance water conservation with carbon uptake. Native desert plants such as Agave and Opuntia use Crassulacean Acid Metabolism (CAM) photosynthesis, opening their stomata at night to minimize water loss while storing carbon dioxide for daytime photosynthesis (Alengebawy A, et al. 2021). Osmotic adjustment, through the accumulation of compatible solutes like proline, glycine betaine, or sugars, enables plants to maintain cellular turgor under drought or salinity stress. Heat-shock proteins and Late Embryogenesis Abundant (LEA) proteins stabilize cellular structures and enzymes under thermal and dehydration stress. Antioxidant enzymes such as superoxide dismutase, catalase, and peroxidase mitigate oxidative damage caused by reactive oxygen species during extreme conditions. Native halophytes exhibit salt sequestration strategies, compartmentalizing sodium ions into vacuoles or secreting them through specialized salt bladders, thus protecting metabolic processes (Fashola MO, et al. 2016).

The ecological significance of these adaptations extends beyond individual survival. Native species anchor ecosystems by maintaining productivity, stabilizing soils, providing habitat, and supporting pollinators and herbivores even under adverse conditions. Their resilience sustains ecosystem functions that humans rely upon, from clean water and fertile soils to timber, medicines, and genetic resources. Furthermore, lessons from native plants offer profound applications in agriculture. As climate change threatens global food security, breeding programs increasingly turn to wild relatives of crops, which often harbor genetic traits for drought tolerance, salinity resistance, or pest resilience. For example, wild relatives of wheat and barley provide alleles for heat and drought resistance, while wild legumes offer traits for symbiotic nitrogen fixation under stress (Maestri E, et al. 2002). Harnessing the genetic diversity of native species is a promising avenue for developing climate-resilient crops capable of sustaining yields under extreme conditions.

Conclusion

Native plant species embody the legacy of evolutionary adaptation to climate extremes, offering invaluable lessons for science, conservation, and agriculture. Through diverse morphological, physiological, biochemical, and phenological strategies, they withstand drought, heat, flooding, salinity, cold, and fire, maintaining genetic diversity and ecosystem stability. Studying these adaptations not only deepens our understanding of ecological resilience but also provides practical solutions for human challenges, from developing climate-resilient crops to restoring degraded ecosystems. However, protecting native species and their habitats is essential to preserve this knowledge and resource base, as anthropogenic pressures threaten their survival. The integration of traditional knowledge, modern science, and conservation strategies will be crucial in harnessing the adaptive wisdom of native plants. Ultimately, learning from native species is not just about admiration of their resilience but about applying these lessons to secure food systems, sustain biodiversity, and build resilient societies in an era of climate uncertainty. The story of native plants is a testament to life's capacity for adaptation and a guide for humanity's path toward sustainability under extreme and unpredictable climates.

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Conflict of Interest

The authors declare no conflict of interest.

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