ScienceDirect

Plant Science

Volume 367, June 2026, 113113

Physiological limits and adaptive responses of the Wetland species *Acorus calamus* (L.) to gradient drought stress: Insights from photosystem II dynamics and oxidative damage

Pallavi Nautiyal [a], Athira Raveendran [a], Vijay Laxmi Trivedi [a], Arvind Singh Farswan [b], M.C. Nautiyal [a]

Show more

Share Cite

https://doi.org/10.1016/j.plantsci.2026.113113

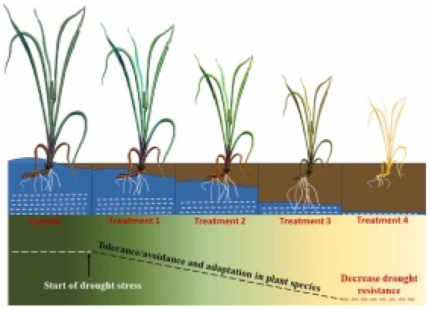
Highlights

- Understanding plant adaptations to water scarcity is vital for conserving and managing wetlands under harsh conditions.
- The study used a semi-controlled setup to assess *Acorus calamus* under drought stress, revealing key adaptive traits.
- The study of *Acorus calamus* responses to drought stress revealed physiological, morphological, and biochemical changes.
- Findings enhance knowledge of wetland responses to climate change and support improved conservation and management strategies.

Abstract

Wetland plants *Acorus calamus* (L.) face increasing drought pressure due to declining global rainfall. As a key wetland species contributing to ecosystem services such as water filtration, shoreline stabilization, and wildlife habitat provision, understanding its drought responses is essential for predicting wetland vulnerability and informing conservation strategies. This study investigated the physiological, morphological, and biochemical responses of *A. calamus* to varying levels of drought stress. Multiple drought-responsive parameters were assessed, revealing significant changes in photosynthetic pigments, morphological traits, and stress indicators, including malondialdehyde and proline. With increasing drought severity, leaf gas-exchange parameters such as net photosynthesis, transpiration rate, stomatal conductance, water use efficiency, and intrinsic water use efficiency declined significantly ($p < 0.001$). Functional traits, including leaf area, leaf area index, leaf area ratio, and specific leaf weight ratio, also showed significant reductions ($p < 0.001$). In contrast, root length, total phenolic content, soluble sugars, starch, proline, and malondialdehyde increased progressively with drought stress. These findings revealed that *A. calamus* undergoes pronounced physiological and biochemical limitations under drought conditions, highlighting the sensitivity of wetland plants to water shortage and underscoring the vulnerability of wetland ecosystems under ongoing climatic change.

Graphical Abstract



Download: Download high-res image (157KB)

Download: Download full-size image

Introduction

Drought is a global climate phenomenon, widely recognized as one of the most destructive risks posed by nature (Guo et al., 2020). Global warming, along with associated climate change-driven factors, is expected to become more consistent and severe in the interior of some continents (Seleiman et al., 2021). Even slight increases in precipitation may be countered by global warming through increased evapotranspiration, which may lead to additional reductions in soil moisture (Wahab et al., 2022). Soil moisture depletion can significantly impact plant growth, even leading to plant mortality. It can also have negative consequences for ecosystems, especially wetland ecosystems, as highlighted by Guo et al. (2020). Since wetlands are often located in a transition zone between an aquatic and a terrestrial ecosystem, their hydrological fluctuation is inevitable. The hydrological fluctuation in wetlands, exacerbated by climate change, urbanization, and changes in land use, can lead to drought stress in wetland plants despite their general resilience to change (Sati et al., 2025, Dodangeh et al., 2025). Earlier reports revealed the different patterns of habitat shifts of wetland plant species, *viz. Bruguiera gymnorhiza* (Liao et al., 2025), *Glyptostrobus pensilis* (Ye et al., 2022), *Metasequoia glyptostroboides* (Li et al., 2025), *Leersia hexandra, Carex doniana* (Cao et al., 2020). While responding to global environmental change, these species exhibit a pattern of both growth and instability due to alterations in precipitation levels (Cao et al., 2020; Sati et al., 2025). Some other wetland plants respond to drought stress by decreasing their above-ground biomass. According to the study by Charles et al. (2009), *Artemisia maritima, Juncus gerardii, Elymus pycnanthus, Festuca rubra*, and *Armeria maritima* showed less biomass production when exposed to water-deficient conditions. Drought stress in plants is initiated when the rate of water loss from leaf surfaces exceeds the rate of water absorption by roots (Siddiqui et al., 2021). Additionally, these conditions can affect plants' water potential and turgor pressure, possibly affecting their life processes, resulting in morphological, biochemical, and physiological changes. It has been shown in previous studies that as drought stress increases, various plant characteristics, such as height, leaf thickness, leaf width, and leaf length, tend to decrease (Jia et al., 2018, Stirling et al., 2020). However, the root architecture exhibits contrasting patterns, with root length, root number, and thickness increasing under drought stress (Dehghani & Bidgoli, 2018).

Various physiological parameters in plants, such as stomatal conductance (Gs), photosynthetic rate (Pn), transpiration rate (E), and intercellular CO_2 concentration (Ci) (Wang et al., 2018), are severely affected by drought. One of the primary impacts of drought on plants is decreasing and suppressing photosynthesis. Research additionally shows that Chlorophyll fluorescence can be a valuable and efficient way to assess the level of stress in plants (Aazami et al., 2021). Based on previous reports, there was a decrease in the maximum photochemical efficiency (Fv/Fm), while the initial fluorescence (F0), non-photochemical quenching (NPQ), and quantum yield (ΦNPQ) showed an increase under drought conditions (Wang et al., 2018, Liang et al., 2020, Chen et al., 2023, Qiao et al., 2024). Drought stress can also alter plant biochemical traits, leading to modifications in various metabolic pathways and biomolecules. Guo et al. (2016) observed that drought treatments resulted in a reduction in the levels of chlorophyll (Chl) a, b, and Chl (a+b) in *Lycium ruthenicum*. Growth, maximum quantum yield, stomatal conductance, CO_2 assimilation, transpiration rates, and electron transport were decreased. In contrast, when exposed to drought stress, there was an increase in non-photochemical quenching, intercellular CO_2, and photorespiration rates in *Lotus corniculatus* (Ünlüsoy et al., 2023). Understanding the process of osmotic adjustment is crucial for the plant to effectively regulate turgor pressure even when faced with low water potential. This ability is vital for the plant to sustain its metabolic functions. Another critical factor in plants experiencing drought stress is malondialdehyde (MDA). According to a previous study by Alam et al., 2014, Alam et al., 2014, the levels of proline and MDA were found to increase in *Brassica* species as drought stress increased.

This study examined the morpho-physiological adaptation of wetland plant species *Acorus calamus* (Sweet flag) under different levels of drought conditions. The plant species central to this investigation is a perennial wetland monocot belonging to the Acoraceae family. The plant is characterized by sword-shaped aromatic leaves and rhizomes rich in secondary metabolites such as β-asarone, α-asarone, flavonoids, and essential oils, which underpin its use in traditional medicine systems like Ayurveda and Traditional Chinese Medicine for gastrointestinal, neurological, and antimicrobial applications (Singh et al., 2014). Ecologically, *A. calamus* plays a key role in wetland dynamics by purifying water, preventing erosion, and providing microhabitats for diverse organisms (Mishra et al., 2017). Its adaptations, including aerenchyma tissues that facilitate oxygen diffusion, make it highly tolerant to waterlogging; however, its dependence on water renders it sensitive to drought stress (Yuan et al., 2018). With increasing incidences of drought due to climate change, studying its physiological and biochemical responses under water-deficit conditions is of great importance (Ye et al., 2022. For *A. calamus*, such stress may also influence secondary metabolite biosynthesis, potentially altering its medicinal value (Li et al., 2012). Understanding these mechanisms is critical for both wetland conservation and sustainable cultivation. Moreover, since wetlands act as carbon sinks and biodiversity hotspots, the decline of drought-sensitive species like *A. calamus* could impair ecosystem services (Zhang et al., 2025). Therefore, evaluating its drought tolerance at physiological, biochemical, and ecological levels will contribute not only to medicinal plant research but also to broader ecological resilience and climate adaptation strategies (Li et al., 2015). We hypothesized that progressive drought would impose staged physiological constraints on *A. calamus*, with partial compensatory responses under mild–moderate stress followed by functional impairment and photoinhibition under severe drought. This plant naturally inhabits environments that experience fluctuating water levels, including periods of drought. Increased frequency and intensity of droughts are predicted in many regions globally (Hu et al., 2024), putting wetland species like *A. calamus*, which depend on consistent water availability, at risk, making it interesting to investigate how it handles water stress. The limited number of studies inhibits our understanding of the key response of *A. calamus* under drought conditions. Thus, it is important to know what the physiological, morphological, and biochemical limitations of *A. calamus* are under drought conditions. The alterations in leaf area, plant height, gas exchange parameters, and biochemical composition will underscore the plant's responses to water shortage. The results of this study can offer significant information about the ability of *A. calamus*, a vital species in wetland ecosystems, to withstand the impacts of climate change.

Section snippets

Plant material and experimental setup

Rhizomes of *A. calamus* L. were obtained from the wild (30º12’03’’N 78º46’20’’E; 710 m ASL), Srinagar, Garhwal, Uttarakhand, India, and transplanted in experimental plots under semi-controlled conditions (glasshouse) at the High-Altitude Plant Physiology Research Center, H.N.B. Garhwal University, Srinagar-Garhwal, Uttarakhand (India) during March 2023 (560 m ASL). Rhizomes were cut into five-centimeter lengths and potted in a semi-controlled environment where various levels of drought stress …

Effect of drought stress on Morphological parameters and plant growth attributes

Leaf length (LL) was significantly affected by drought treatment ($P < 0.001$), declining from 73.51 ± 4.21 cm under control conditions (100% FC) to 39.07 ± 1.03 cm under extreme drought (10% FC), representing a 46.85% reduction (Fig. 2). Root length (RL) varied significantly across treatments ($P < 0.001$). RL increased from 20.33 ± 1.21 cm in control plants to 48.23 ± 2.32 cm under severe drought (25% FC), corresponding to a 137.24% increase relative to control. However, RL declined under extreme …

Discussion

Plants experience various environmental stresses throughout their life cycle, both in natural and agricultural settings. Considering the constantly shifting environmental conditions, wetland plants may encounter a range of stresses that can significantly impact their development and growth (Pandey et al. 2023). Wetland plants show a range of physiological responses to drought stress, ranging from short-term compensatory adjustments under mild water limitation to progressive functional …

Conclusion

The present study examined the effects of drought stress on *A. calamus* (L.) by assessing changes in physiological, morphological, and biochemical traits under varying levels of water availability. Progressive drought induced marked alterations in leaf area, plant height, gas-exchange characteristics, and metabolic indicators. Significant declines were observed in photosynthetic pigments, morphological attributes, and physiological performance, alongside increases in stress markers such as …

CRediT authorship contribution statement

Arvind Singh Farswan: Visualization, Validation, Data curation. **M C Nautiyal:** Writing – review & editing, Supervision. **Athira Raveendran:** Visualization, Methodology, Investigation. **Vijay Laxmi Trivedi:** Writing – review & editing, Validation, Resources, Project administration, Conceptualization. **Pallavi Nautiyal:** Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. …

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. …

References (57)

B. Abbaszadeh *et al.*
Improving water use efficiency through drought stress and using salicylic acid for proper production of *Rosmarinus officinalis* L
Ind. Crops Prod. (2020)

F. Araniti *et al.*
Impact of cyclic-mild-drought stress on the metabolism of *Mentha spicata* L.: A strategy to improve quality traits
Ind. Crops Prod. (2024)

F. Bussotti *et al.*
Selection of chlorophyll fluorescence parameters as indicators of photosynthetic efficiency in large-scale plant ecological studies
Ecol. Indic. (2020)

D. Christen *et al.*
Characterization and early detection of grapevine (*Vitis vinifera*) stress responses to esca disease by in situ chlorophyll fluorescence and comparison with drought stress
Environ. Exp. Bot. (2007)

H.J. Earl
Stomatal and non-stomatal restrictions to carbon assimilation in soybean (*Glycine max*) lines differing in water use efficiency
Environ. Exp. Bot. (2002)

O. Herlory *et al.*
Sensitivity evaluation of the green alga *Chlamydomonas reinhardtii* to uranium by pulse amplitude modulated (PAM) fluorometry
Aquat. Toxicol. (2013)

S. Hu *et al.*
Greenhouse gas emissions and carbon budget estimation in horizontal subsurface flow constructed wetlands with different plant species
Sci. Total Environ. (2024)

J. Jia *et al.*
Effects of drought and salt stresses on growth characteristics of euhalophyte Suaeda salsa in coastal wetlands
Phys. Chem. Earth (2018)

S. Kumar *et al.*
Water resources pollution associated with risks of heavy metals from Vatukoula Goldmine region, Fiji
J. Environ. Manag. (2021)

A. Mishra *et al.*
Role of wetland plants in maintaining ecosystem functions
Environ. Rev. (2017)

View more references

Cited by (1)

Integrated sustainability assessment of hydroponic, aeroponic, and geoponic systems for Acorus calamus cultivation: A life cycle and techno-economic analysis
2026, Journal of Cleaner Production

Show abstract

View full text