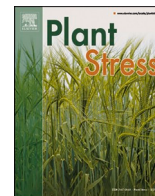




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Editorial

Impact of climate change in viticulture: understanding and mitigating abiotic and biotic stress in grapevine

A B S T R A C T

Grapevine is one of the most important crops worldwide for economic value. Multiple abiotic stresses, including drought, heatwaves, soil salinity, increasingly threaten grapevine cultivation, critically impacting vine health, fruit yield and grape quality. Furthermore, biotic stresses caused by bacteria, fungi, viruses, nematodes, and insects are increasing, exacerbated by climate change. Several efforts have been made in recent years to understand and mitigate the effects of climate change in a significant economic context, such as viticulture. This special issue aimed to consolidate recent advancements in the field of grapevine stresses, and possibly identifying new potential mitigation strategies at agronomical, physiological, eco-physiological and molecular level, involved in the grapevine response to abiotic and biotic stresses.

Introduction

Grapevine (*Vitis* spp.) is a pivotal crop for global agriculture, although its cultivation is increasingly constrained by interacting abiotic and biotic stresses driven by climate change. Increased temperatures and altered seasonality have already shifted vine phenology and berry ripening timing in many regions, with major consequences for wine typicity and cultivar suitability (Duchêne et al., 2010; Van Leeuwen and Darriet, 2016). These consequences are particularly profound in Mediterranean and semi-arid areas, prompting research on locally adapted genotypes and agronomic techniques (Delrot et al. 2020; Naulleau et al. 2021). Heatwaves, drought and salinity impair photosynthesis, carbohydrate partitioning and secondary-metabolite accumulation, with cultivar-dependent outcomes for berry composition and quality (Calderan et al., 2021; Palai et al., 2023; Rogiers et al., 2022; Mirás-Avalos et al., 2018). Concurrently, trunk and foliar diseases as well as pathogen pressure are increasing due to the often more favorable climatic conditions (Kenfaoui et al. 2022; Rienh et al., 2021; Weiller et al., 2021). In this regard, symbiotic and endophytic organisms, especially arbuscular mycorrhizal fungi and bacterial consortia, can modulate host nutrition, water relations, defense priming and pathogen incidence, offering promising mitigation options (Ganugi et al., 2023; Velaz et al., 2025). At the plant level, root anatomy and biomechanics, ion homeostasis and osmotic adjustment are fundamental mechanisms to cope with salinity and drought (Alonso-Forn et al., 2025; Lai et al. 2025; Song et al., 2024). At molecular level, integrative omics and physiological studies reveal coordinated shifts in primary metabolites such as sugars, organic acids, amino acids and lipid signaling under combined stresses (Serrano et al., 2017; Brito et al., 2022; Martínez-Lüscher et al., 2025). Also, secondary metabolites determination enables earlier, non-destructive detection of abiotic stress and biotic infection, accelerating screening and precision interventions (Konecny

et al., 2025; Khan et al., 2023). This special issue aimed to collect new insights and outcomes from mechanistic molecular studies to field-relevant ecophysiology and applied microbiome/phenotyping approaches, to increase the fundamental understanding and the applicable mitigation strategies for grapevine under different stresses.

Papers in this special issue

The papers in this special issue cover different abiotic and biotic stress impacting viticulture. Most of the papers focused on drought and salt stress, whereas different aspects of the pathogens defense strategy and mycorrhizal symbiosis beneficial effects were faced as well. Some papers included in the special issue also covered other specific aspects such as iron deficiency, intercropping and thermal and light stresses. Barrientos-Sanhueza et al. (2025) evaluated root biomechanical responses to short-term salinity stress in commercial rootstocks and hyper arid-adapted Chilean genotypes. Salinity disrupted tissue load-bearing capacity in rootstocks, while the adapted genotypes preserved elasticity and resilience. Results highlighted the importance of root biomechanics in stress adaptation and as a breeding guideline for salt-tolerant grapevines genotypes. Montanaro et al. (2025) examined physiological and phenotyping data distinguishing drought from salinity stress. Salt stress induced strong non-stomatal limitations to photosynthesis, unlike drought. The results identified maximum photosynthetic efficiency (F_v/F_m) and leaf dark-green color as reliable markers for early, non-destructive stress type detection in high-throughput phenotyping. Reta et al. (2025) evaluated salinity stress effects in Syrah grapevines grafted on SO4 rootstock. The authors reported how the accumulation of Cl^- and Na^+ in the plant organs was accompanied by an ions unbalance and metabolic adjustments. Declines in stomatal conductance and photosynthesis and the associated unbalance of K^+ , Mg^{2+} , Fe^{2+} , Zn^{2+} , and Cu^{2+} , occurred above 1.5 dS m^{-1} determining a tipping point for the

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salinity response in the cultivar Syrah. Patin et al. (2025) presented the results of root traits of diverse wild *Vitis* species associated with drought responses. Three constitutive root syndromes were identified, with distinct associations to shoot performance under drought. Some North American and Asian *Vitis* species showed strong osmotic adjustment and biochemical plasticity. Findings highlighted unexplored root diversity as a key resource for breeding drought-adapted rootstocks. Lu et al. (2024) in a comparative analysis of NF-Y transcription factors family in *Vitis vinifera* L. and *Vitis amurensis* Rupr. identified stress-responsive candidates. Overexpression of VaNF-YA6 enhanced salt and drought tolerance by regulating stress-related genes and enzyme activities. The study provided a molecular basis for exploiting NF-Y transcription factors family, particularly VaNF-YA6, to improve grapevine stress resilience. Lehr et al. (2025) evaluated the effect of sulfate fertilization on water stress in grapevine and in maize, both indicated as model plants. The authors targeted the leaf and the guard cells of the stomata, identifying a metabolism distinct from that of the whole leaves. Drought stress induced an increase in leaf sulfate concentration in maize even in the absence of external sulfur supply, indicating an intrinsic activation of sulfate metabolism as part of its endogenous drought response. In contrast, grapevine exhibited enhanced leaf sulfate accumulation and improved drought acclimation only when additional sulfate was provided, revealing a stronger dependence on external sulfur availability to sustain metabolic adjustments under water deficit. Within the papers focused on the grapevine beneficial symbiosis with mycorrhizal against abiotic stresses, Belval et al. (2024) reported that mycorrhization of *Vitis vinifera* L. with *Rhizophagus irregularis* enhanced tolerance to *Neofusicoccum parvum*, reducing wood necrosis and stabilizing lipid metabolism. Metabolomics analysis also revealed reprogramming of sugars, stilbenes, and fatty acids biosynthesis. Thus, these findings suggested that arbuscular mycorrhizal fungi symbiosis may improve vine resilience against trunk disease fungi by harnessing metabolic adjustments. In a review study, Valenzuela-Aragon et al. (2025) highlighted the role of arbuscular mycorrhizal fungi in enhancing grapevine adaptation to abiotic stresses. The arbuscular mycorrhizal fungi also improve nutrient and water uptake, photosynthesis, and soil health, while reducing chemical inputs. Challenges remain in ensuring consistent vineyard performance, but integration with precision viticulture offers interesting potential for sustainable stress management. New insights related to pathogens and biotic stress were also analyzed by some papers included in the special issue. Nepi et al. (2025) evaluated the volatile organic compounds (VOC) emitted by intact grape berries infected with *Botrytis cinerea*. Inoculated berries released higher levels of primary and secondary alcohols, some of them novel as infection markers. Results also suggested that VOC-based sensors could enable early detection of grey mold in dehydration chambers, reducing spoilage and grape losses. Sandrini et al. (2024) tested a grapevine-derived endophytic bacterial consortium (SynCom) against major grapevine pathogens. SynCom reduced wood-decay pathogen abundance but slowed photosynthesis, suggesting defense mechanism activation. In contrast, a commercial consortium of arbuscular mycorrhizal fungi and *Bacillus coagulans*, which was further tested in the same experiment, supported a more balanced physiological response. Overall, results demonstrated the potential of tailored endophyte consortia for grapevine protection and highlighted trade-offs in plant-microbe interactions. Del Frari et al. (2025) reported that the esca-affected grapevine leaves displayed distinct symptom phenotypes linked to shifts in endophytic fungal communities and anthocyanin composition. In addition, DNA metabarcoding revealed cultivar- and vintage-dependent microbial diversity changes. Other papers included in this special issue focused on specific abiotic stresses which occur in grapevine. Zha et al. (2024) examined temperature and light effects on grape berry quality during ripening. High temperature promoted sugar accumulation but caused fruit softening, while low light reduced sugars without softening. Both factors altered anthocyanin metabolism via the COP1-HY5-FLS4 pathway. Kita et al. (2024) evaluated the seasonal freezing resistance of two *Vitis*

vinifera cultivars and the hybrid “Maeve” in the subarctic Hokkaido region. Maeve vines showed higher winter freezing resistance, linked to earlier water content reduction and higher sucrose and monosaccharide accumulation. Khalil et al. (2025) investigated the responses of tolerant (Fercal) and susceptible (3309C) grapevine rootstocks to iron deficiency. Bicarbonate-induced stress caused more severe effects than direct iron shortage. Fercal, a rootstock with *Vitis vinifera* genes that gives higher resistance to lime, showed higher adaptability via increased root biomass, organic acid accumulation, and stronger activation of iron transport genes. Finally, Campillos et al. (2024) evaluated an intercropping strategy with rosemary in a Mediterranean vineyard. Berry soluble sugars, titratable acidity, and phenolic compounds were not influenced by intercropping while rosemary had higher berry antioxidant level, particularly at harvest. The study concluded that intercropping grapevines with rosemary did not negatively impact plant physiological performance or grape quality, promoting the production of two high-quality products with significant added value.

Concluding thoughts

This special issue of *Plant Stress* highlights how multiple stressors are currently threatening the grapevine cultivation, and the scientific community is testing them with multiple scientific tools including: molecular biology, the organ-specific physiological response, microbiology and metabolomics. Some of the articles studied pathogen detection and endophytic consortia, highlighting how these new innovative approaches could have potential practical implications in early detection and pathogen defense. The papers that examined grapevine eco-physiology, osmotic regulation and drought adaptation provided novel insights into mechanisms involved in the tolerance to drought and salt stress, which are known to be the major threats for the modern viticulture also considering future implications related to global warming. A complementary approach, which integrates eco-physiology, genomics, metabolomics, precision viticulture and microbiome-based strategies with innovative agronomic practices represents the leading way enabling grapevine to effectively withstand the combined pressures of abiotic and biotic stresses in a changing climate.

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