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Editorial: Abiotic stresses in field crops: response, impacts and management under climate change scenario

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Editorial on the Research Topic
Abiotic stresses in field crops: response, impacts and management under climate change scenario

Agriculture faces significant challenges from environmental factors like drought, heat, waterlogging, cold, soil salinity, nutrient deficiency, and heavy metal contamination (Pathak, 2023). These stresses impair plant function, limiting growth and productivity. With climate change increasing the frequency and intensity of these stresses, food and nutrition security are at risk. Plants employ various tolerance mechanisms at molecular, biochemical, physiological, and morpho-anatomical levels, which vary by species and stress type (Rane et al., 2021). This editorial highlights promising research showcasing advanced understanding of plant responses to abiotic stresses. Through 14 publications (13 original research and 1 review) editorial covers various aspects of managing the emerging and future abiotic stresses through innovative G × E × M (genotype by environment by management) practices for improving the tolerance as well as adaptation and mitigation strategies for enhanced sustainability of crop production systems.

Oat (*Avena nuda* L.) is a moderately salt-tolerant cereal crop, and understanding its salinity tolerance mechanisms can improve production in salt-affected areas. Liu et al. studied the salt tolerance of the naked oat line Bayou1, treating 17-day-old seedlings with varying NaCl concentrations for 12 days. Optimal growth was observed at 50 mM NaCl. Despite reduced water uptake and nutrient imbalances, Bayou1 maintained root growth, indicating roots play a key role in its salt tolerance through increased Na^+ concentrations in root cell sap while maintaining membrane integrity and osmotic potential.

Azrai et al. applied machine learning (ML) to predict maize grain yield and stress tolerance index (STI) under normal and drought conditions. Thirty-five genotypes were evaluated across three sites, and ML models were optimized using genetic algorithms (GA) and ensemble methods. Results showed that ensemble models optimized by grid search had the best performance, with R^2 values of 0.92 for grain yield and 0.82 for STI. The Multi-trait Genotype-Ideotype Distance (MGIDI) approach accurately identified superior hybrids (H06, H10, H13, H35), highlighting the potential of ML and MGIDI in drought-tolerant maize breeding.

Excess soil iron (Fe) toxicity is a major challenge for rice cultivation in acidic soils. Sonu et al. assessed sixteen rice genotypes under varying iron (Fe) levels to evaluate their responses to Fe toxicity, focusing on seedling root systems. Hydroponic screening identified 460 ppm Fe as a critical threshold, significantly affecting root traits and biomass. Genotypes were classified into tolerant and sensitive categories using leaf bronzing scores and a response stability index. Tolerant varieties, such as ILS 12-5, were identified, while popular varieties like BPT 5204 and Pusa 44 showed high sensitivity to Fe toxicity.

Traditional rice monocropping in uplands is not environmentally sustainable and profitable. Pan et al. assessed the energy flow, carbon balance, and GWP of five monocropping systems (rice, finger millet, black gram, horse gram, pigeon pea) and four intercropping systems (rice+black gram, rice+horse gram, finger millet+black gram, finger millet+horse gram). Rice+black gram and rice+horse gram were the most energy-efficient, with better carbon efficiency and sustainability. Pigeon pea and finger millet+horse gram offered higher rice equivalent yields and benefit-cost ratios. Overall, pigeon pea and finger millet-based intercropping systems were the best options for eastern India's rainfed upland agro-ecosystem.

High carbon losses in Mollisols pose a substantial challenge to food security and climate regulation. Liang et al. assessed fertilization strategies on crop yield, soil organic carbon (SOC) stock, and carbon sequestration efficiency under climate change scenarios in Northeast China using the SPACSYS model. Higher temperatures reduced maize yield by 14.5% in Harbin and 13.3% in Gongzhuling, and soybean yield by 10.6%. SOC sequestration efficiency decreased with increased carbon input. Manure application resulted in higher carbon sequestration efficiency compared to other treatments, making it an effective practice for climate change mitigation in Mollisols.

Basavaraj et al. screened cowpea varieties for waterlogging tolerance by evaluating morpho-physiological and root traits under 10 days of waterlogging stress at the seedling stage. Waterlogging reduced plant height, leaf area, chlorophyll content, and NDVI, but tolerant varieties like DC15 and PL4 exhibited increased adventitious root (AR) number and length. Correlation and PCA analyses revealed a positive link between AR formation/length and waterlogging tolerance, suggesting these traits as valuable markers for breeding waterlogging-tolerant cowpeas.

Smallholder maize farming in sub-Saharan Africa is highly vulnerable to drought, threatening food security and livelihoods. Ndlovu et al. mapped genomic regions associated with water stress tolerance in tropical maize using three F3 populations (753 families) evaluated in Kenya and Zimbabwe. High-density SNP markers identified 93 QTLs under well-watered and 41 under water-stressed conditions, with significant QTLs for grain yield, plant height, ear height, and anthesis-silking interval. These findings highlight the potential of genomic selection for improving maize breeding to enhance drought tolerance and support food security in sub-Saharan Africa.

Drought is a major concern in chickpea breeding, controlled by multiple genes. Harish et al. examined 125 chickpea landraces from the West Asia and North Africa (WANA) region, and 4 varieties, to identify marker-trait associations (MTAs) and candidate genes for drought tolerance. Thirteen physio-morphological traits were analyzed over two years at two locations, revealing strong correlations between seed yield and biological yield. Using genotypic data from 6,367 SNPs, 52 significant SNPs were identified, including genes related to drought tolerance such as GHR1, WAT1, and beta-galactosidase, which will aid in improving drought tolerance in chickpea breeding.

Cadmium (Cd) contamination in agricultural soils is a global concern due to its harmful effects on human health. Iqbal et al. investigated the impact of vermicompost (VC) on soil properties, plant physiology, leaf ultrastructure, antioxidant defense, and rice yields under Cd stress. Results showed that Cd toxicity decreased soil quality, photosynthesis, and antioxidant activity, leading to lower rice yields. However, VC application improved soil health, enhanced physiological functions, and boosted antioxidant enzyme activities, reducing Cd uptake and alleviating oxidative damage. The treatment (50 mg Cd + 6 t ha^{-1} VC) significantly increased grain yields, highlighting potential of vermicompost towards sustainable rice production in Cd-contaminated soils.

Climate change directly affects cotton yield by damaging morphological development and plant growth. Fan et al. used the AquaCrop model and 30 years of meteorological data (1988–2017) to optimize irrigation and planting dates for cotton under limited water conditions. Results showed that higher irrigation quotas increased yield and biomass, with 495 mm achieving optimal water efficiency. Planting in late March to early April suits regions with abundant water, while late April to early May is better for water-scarce areas, using early-maturing varieties.

Continuous drought stress threatens food security, yet crop responses remain uncertain. Cui et al. calibrated and validated the AquaCrop model using summer maize data from 2017 to 2018 to simulate growth under various drought scenarios. The model analyzed transpiration (Tr), biomass accumulation, and yield formation at two growth stages. Results showed that drought at the seedling stage significantly reduced transpiration and biomass, with severe drought during the seedling and jointing stages causing total yield loss. The study emphasized the importance of avoiding severe drought at these stages for sustainable maize yield.

Chakrabarti et al. investigated the effects of elevated ozone (O_3) and carbon dioxide (CO_2) on rice productivity in northern India over two kharif seasons (2020–2021). Using Free Air Ozone-Carbon dioxide Enrichment (FAOCE) rings, three rice varieties (Pusa Basmati 1121, Nagina 22, IR64 Drt1) were examined under varying nitrogen (N) management. Elevated O_3 reduced photosynthesis, stomatal conductance, and transpiration, resulting a 6.9–9% yield reduction. Elevated CO_2 partially compensated for yield losses, particularly in Nagina 22. Additional N (125% RDN) improved grain N uptake under elevated O_3 and CO_2 conditions.

Siddiqui investigated the effects of cypermethrin, a widely used synthetic pyrethroid, on growth, pollen morphology, fertility, and antioxidant activities in *Cicer arietinum* L. The exposure not only reduced plant height, branches, pods, seeds, and yield but also increased pollen wrinkling, reduced fertility, impacted chlorophyll and carotenoid content. Cypermethrin also affected hydrogen peroxide scavenging, lipid peroxidation, and antioxidant enzyme activities in a dose-dependent manner. These findings highlight the need for further research on the ecological and health risks of cypermethrin exposure.

Wang et al. conducted a review on drought and heat stress in perennial ryegrass (*Lolium perenne* L.) from 1994 to 2024 showcasing consistent publications from China and the USA. Keyword analysis revealed "growth," "endophytic fungi," and "yield" in drought studies, while "growth," "gene," and "leaf" were common in heat stress research. Most studies focused on phenotype, resistance mechanisms, and endophytes. The review emphasized the need for further molecular research on drought-heat stress interactions.

Overall, this comprehensive range of research highlights the need for a multifaceted approach to understand the interactions and impacts of combined stresses, crucial for developing stress-tolerant crops and devising mitigation strategies for various climatic challenges.

Author contributions

AP: Conceptualization, Writing – original draft, Writing – review & editing. AD: Supervision, Writing – review & editing. ML: Writing – review & editing. MK: Writing – review & editing. MA: Writing – review & editing. PB: Writing – review & editing. KP: Supervision, Writing – review & editing.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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