Exploring Silicon's Role in Mitigating Drought and Heat Stress in Wheat

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ABSTRACT

Global wheat production faces significant challenges due to climate-induced drought and heat stress, which adversely affect grain filling, photosynthesis, and yield. This study investigated the role of silicon in mitigating these stresses through physiological, morphological, and biochemical pathways. Experiments were planned in Australia and Mexico under controlled and field conditions. Drought and heat stress were applied using set protocols. Data were recorded for agronomic, physiological and biochemical traits. Results demonstrated that silicon (Si) application enhanced resilience by improving water-use efficiency, chlorophyll fluorescence, and osmolyte accumulation while reducing oxidative damage which leads to improved grain yield. Field trials confirmed Si's efficacy in maintaining yield-related traits, reducing canopy temperature, and extending the stay-green phenotype. These findings underscore Si's potential as a sustainable intervention to enhance wheat productivity in rainfed systems, offering a viable strategy for addressing food security challenges in climate-stressed regions.

Keywords: Triticum Aestivum, Si, Water Stress, High Temperature Stress.

INTRODUCTION

Global wheat production is under significant threat due to climate change, particularly in established agricultural regions, raising concerns about future food security. Temperature and water availability are critical factors influencing yield in rainfed cropping systems. Among environmental constraints, drought and heat stress—both individually and in combination—pose severe challenges to wheat growth and productivity. These stresses result in reduced photosynthesis, oxidative damage to cell organelles, early senescence, shortened plant lifecycles, spikelet infertility, kernel abortion, decreased grain weight, and reduced overall yield. The combined effects lead to shorter grain-filling periods, reduced carbohydrate reserves, smaller grain size, and diminished yields.

Silicon (Si) is the second-most abundant element in the Earth's crust, primarily found as silicates. Although not classified as an essential nutrient, Si has been shown to improve plant growth and resilience under stress conditions. Plants absorb Si in the form of mono-silicic acid (H_4SiO_4) through aquaporin channels under acidic to neutral pH conditions. Silicon concentrations in plants can range from 0.1% to 10% of shoot dry weight. Research indicates that Si accumulation enhances resilience to abiotic stresses by reducing oxidative damage, increasing antioxidant activity, improving gas exchange, and enhancing nutrient uptake and osmotic regulation (Ashfaq, 2022).

Under this scenario, exploring new mitigation strategies like Si application is essential to elucidate its role under drought and heat stress at physiological and biochemical levels in wheat. The study investigated the mechanisms and interactions in Si-mediated tolerance in wheat against the individual and combined stress of drought and heat at morphological, physiological, and biochemical levels both in control and field conditions. In the climate change scenario, it was expected that this study helps to establish new protocols and alternatives for wheat management under drought and heat stress for sustainable yield production in a rainfed cropping system in Australia and overseas.

MATERIAL AND METHODS

A series of experiments were conducted at the University of Melbourne's Dookie campus and at the International Maize and Improvement Centre (CIMMYT) in Mexico (Figure **1**). The first experiment was conducted to screen out 46 wheat genotypes for drought and heat stress environments using RCB design. Based on the selected genotypes, rest of the experiments were conducted to study the physiological and biochemical responses of drought and heat stress tolerant and susceptible genotypes in response to Si application under drought, heat and combined drought-heat stress conditions. Drought field capacity was maintained at 38±3 for 14 days after the acclimatization period of five days. Heat stress was applied at 36 °C for three consecutive days. Data were analysed using the R software using the R Studio integrated Development Environment.

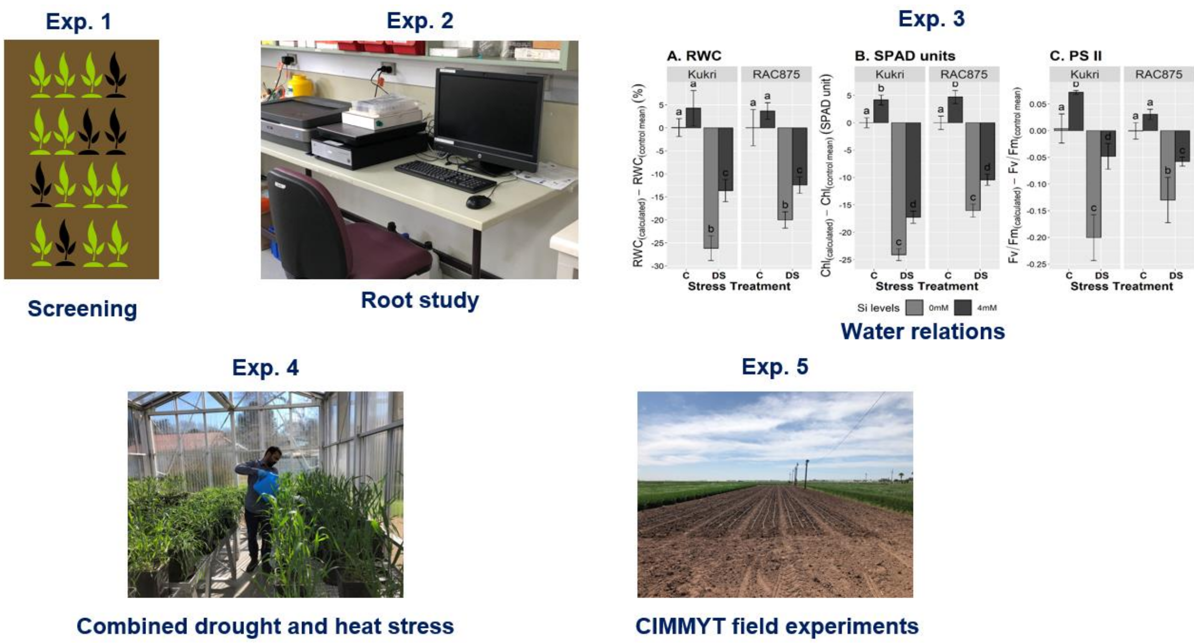

Figure 1. Experiments conducted in controlled and field conditions.

RESULT AND DISCUSSION

Non-destructive thermal imaging and computational water stress indices were employed to classify wheat genotypes for drought and heat stress tolerance, facilitating the identification of promising lines for further research. Results showed that this technique effectively categorized wheat genotypes based on various morphological and physiological traits, highlighting the critical role of precise phenotyping in breeding programs (Ashfaq *et al*., 2022a). Results from the root experiment demonstrated that Si application improved root morphology, water stress indices, and gas exchange traits under drought conditions, demonstrating its role in optimizing plant water use, photosynthesis, chlorophyll fluorescence, and osmolyte accumulation (Ashfaq *et al*., 2024).

Results from combined stress experiment showed that Si alleviated terminal drought, heat and drought-heat combined stress by boosting antioxidant defence mechanisms, osmolytes accumulation and reducing oxidative damage in drought, and heat stress tolerant and susceptible wheat genotypes. Results also showed that computational water stress indices (canopy temperature, canopy temperature depression and crop water stress index) positively changed with Si application under drought and heat stress (Ashfaq *et al*., 2022b). Field trials confirmed Si's benefits for yield-related traits, chlorophyll retention, and canopy temperature regulation, showing its potential for sustainable crop production in stress-prone environments. These findings highlight Si as a valuable tool for improving wheat resilience and productivity in rainfed systems.

CONCLUSION

Collectively, the findings suggest that integrating Si application into wheat cropping systems could mitigate the impacts of climate-induced stress, offering a promising strategy for sustaining food production.

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