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RESEARCH

Temporal Impact of Elevated CO_2 and Temperature on *Solanum Lycopersicum* L.: Insights into Growth, Phenology, Ultrastructure, Nutritional Quality and Metabolite Profile

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Abstract

Increasing atmospheric carbon dioxide levels since industrialization, and rise in global mean surface air temperature has led to adverse effects on crop plants across the world. Altered climatic parameters lead to change in phenology, shift in cropping cycle and change in primary and secondary metabolites of economically important parts of plants. However, only few studies have addressed the responses of vegetable crops to these changes globally. Current study was conducted to assess impact of the CO_2 enrichment, and combined influence of elevated CO_2 and temperature on the growth, phenology, ultrastructure, and primary and secondary metabolites of tomato (*Solanum lycopersicum* L.), at pre-flowering and maturity stage. Tomato was grown in Open Top Chambers at elevated CO_2 (750 ± 50 ppm), and high CO_2 (750 ± 50 ppm) and temperature higher than 2 °C of the ambient. Reduced crop duration, accelerated phenology and decreased biomass were the primary outcomes of exposure to CO_2 and temperature enrichment. While only CO_2 enrichment had some positive effects, high temperature counteracted these, indicating that plants in future may experience stress. We also observed stage-dependent response of tomato to both treatments, suggesting an adjustment in plant's responses. Increased activity of antioxidants indicated activation of stress mitigating mechanism in tomato. Decreased protein levels and increased sugars suggest nutritionally compromised tomatoes in the future. Ultrastructure of the leaf revealed modification of chloroplast microanatomy to accommodate carbon accumulation in the form of starch. The study provides a comprehensive insight into the ultrastructural, biochemical, and phenological responses of tomato plants under projected climate change conditions.

Keywords Scanning electron microscopy · Transmission electron microscopy · Nutritional security · CO_2 fertilization · Oxidative stress · Climate change · Secondary metabolism

Introduction

Anthropogenic emission of Green House Gases (GHG) has led to an unprecedented challenge of global climate change. Mean global atmospheric carbon dioxide concentration [CO_2] has seen a record surge to 422 ppm (parts per million) since industrialization in January 2024, the highest recorded in the last two million years (Mauna Loa Observatory 2024). Among various GHG, the increase in [CO_2] has emerged as a prime concern, with well-

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