New study indicates C_4 crops less sensitive to ozone pollution than C_3 crops

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The SoyFACE research facility near Champaign, IL. The effects of elevated ozoneon soybean, snap bean, maize, and C_4 bioenergy grasses were investigated at this location. Credit: Jim Baltz

Ozone (O_3) in the troposphere negatively impacts crop growth and

development, causing significant decreases in crop yield worldwide. This airborne pollutant does not come directly from smokestacks or vehicles but instead is formed when other pollutants, mainly nitrogen oxides and volatile organic compounds, react in the presence of sunlight. In an increasingly polluted atmosphere, understanding what plants are tolerant of O_3 is critical to improving crop productivity and resilience.

In a collaboration between the Feedstock Production and Sustainability themes at the Center for Advanced Bioenergy and Bioproducts Innovation (CABBI), researchers have studied the effects of elevated O_3 on five C_3 crops (chickpea, rice, snap bean, soybean, wheat) and four C_4 crops (sorghum, maize, Miscanthus × giganteus, switchgrass).

Their findings, published in *Proceedings of the National Academy of Sciences*, indicate that C_4 crops are much more tolerant of high O_3 concentrations than C_3 crops.

"Understanding the tolerance of C_4 bioenergy crops to air pollutants will help us deploy them strategically across landscapes around the world," said Lisa Ainsworth, Research Leader of the U.S. Department of Agriculture Agricultural Research Service's (USDA-ARS) Global Change and Photosynthesis Research Unit and Adjunct Professor of Plant Biology at the University of Illinois.

Both C_3 and C_4 crops are major sources of food, bioenergy, and ethanol production worldwide. The difference between C_3 and C_4 plants lies in the carbon-fixation pathway they use during photosynthesis: C_3 plants convert CO_2 and sunlight into a 3-carbon molecule, whereas the first photosynthesis product of C_4 plants is a 4-carbon molecule.

Additionally, the C_4 photosynthesis pathway starts in mesophyll cells that comprise the surface of the leaf and then moves into bundle sheath cells that are deeper in the plant. This spatial separation is not present in the

C_3 photosynthesis pathway. Scientists have historically assumed that C_4 plants are less sensitive to O_3 pollution than C_3 plants, but that assumption had not been thoroughly researched until this study.

"Variation in size and growing season length means that it is difficult to do side-by-side comparisons of the response of C_3 and C_4 crops to ozone in the field," said Shuai Li, primary author on the paper and a postdoc in CABBI. "This limits accurate comparisons of the O_3 sensitivity of C_3 and C_4 crops."

By synthesizing available literature and unpublished data from crops grown with increased O_3 pollution in open-air field experiments over the past 20 years, authors performed a comprehensive analysis of the impact of O_3 on crop physiology and production in five C_3 crops and four C_4 crops.

"We focused on field experiments and quantified crop responses to a specific increase in O_3 pollution. This new method quantitatively showed that C_3 crops are more sensitive to elevated ozone than C_4 crops," Li said.

The reasoning behind such a conclusion could to do with the differences in leaf anatomical features, stomatal conductance, and/or metabolic rates between the C_3 and C_4 crops. In C_3 plants, reactive oxygen species from O_3 degradation can damage the mesophyll cells where photosynthesis occurs.

In C_4 plants, however, the spatial separation of the C_4 photosynthesis pathway helps prevent O_3 from infiltrating the bundle sheath cells where sugars are made. In addition, C_4 crops generally have lower stomatal conductance than C_3 crops, potentially resulting in less O_3 uptake in C_4 crops. These factors likely account for C_4 plants' superior tolerance of O_3.

"This study enhances our understanding of the mechanisms of crops response to elevated O_3 and highlights practical relevance for crop management and O_3 tolerance improvement," Li said.

Ozone pollution is increasing in many parts of the world. This study quantitatively showed that O_3-induced reductions in plant function and productivity are more severe in C_3 crops than in C_4 crops, likely because O_3 interacts differently with the C_3 and C_4 photosynthesis pathways.

Based on this finding, agricultural lands in polluted environments can be managed to have improved overall performance. C_4 crops, particularly bioenergy feedstocks, can maintain productivity in regions with high O_3.

More information: Shuai Li et al, Similar photosynthetic but different yield responses of C_3 and C_4 crops to elevated O_3, *Proceedings of the National Academy of Sciences* (2023). DOI: 10.1073/pnas.2313591120

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