High concentration of CO_2 protects sorghum against drought and improves seeds

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The rising atmospheric concentration of carbon dioxide (CO_2), chief among the greenhouse gases fueling global warming and climate change, is beneficial for the physiology of sorghum, an economically and nutritionally important crop grown worldwide. This is the conclusion of a study performed at the University of São Paulo's Bioscience Institute (IB-USP) in Brazil.

The researchers found that when sorghum plants were kept in a low-humidity environment, CO_2 not only protected them against drought but also promoted a systemic adjustment in their metabolism that led their seeds to accumulate 60% more protein.

"Like sorghum, other plants suffering drought stress as climate change advances can be protected by rising levels of atmospheric CO_2. While this is an undesirable condition, we can learn a great deal from it about the behavior of sorghum and similar plants, as well as about how to develop improvement strategies," said Marcos Silveira Buckeridge. Buckeridge is the principal investigator for the project "Using systems biology approach to develop a model for whole plant functioning", which is supported by FAPESP and the Microsoft Research.

The discovery contributes to a better understanding of the impact of climate change on sorghum and other grasses such as sugarcane and maize. According to Buckeridge, the study is the first systematic analysis of the effects on sorghum of high concentrations of CO_2 combined with drought to consider the interactions between different organs of the plant.

"While most research in the field focuses on specific parts of plants, such as leaves, stems or roots, we set out to understand sorghum as a system," he said. "We studied the interactions among its organs when subjected to water stress combined with high levels of CO2. Whole-plant metabolism studies of this kind improve our understanding of the implications of modifying several genes or introducing an entire metabolic pathway into one organ, such as a system in the stem that accelerates water transport. This requires investigating what happens not just in the stem but also in leaves, flowers and seeds, producing a broader picture without losing the specific focus on the more reduced level of processes, i.e., the plant's biochemistry."

Sorghum is genetically very similar to sugarcane. It is an excellent model for the study of grasses that are economically more important to Brazil because of the simplicity of its genome, which has been completely sequenced and is available to the international scientific community.

The ability of sorghum to benefit from rising CO2 levels is due to a peculiarity of photosynthesis in the family of C4 grasses, which include sugarcane and maize as well as sorghum. C4 photosynthesis uses a supplementary method of CO2 uptake in which a 4-carbon molecule is formed instead of the two 3-carbon molecules involved in the more widespread C3 process.

"The C4 photosynthesis found in grasses is a highly efficient system that leads to anatomical and biochemical modifications in their leaves, enabling them to make more efficient use of CO2," Buckeridge said.

To analyze the interactions among plant organs during the process, Buckeridge's team at IB-USP, in collaboration with researchers at the Ohio State University in the United States, performed metabolomics studies on sorghum to investigate all the metabolites produced or modified under specific conditions, as well as gene functions and interrelations, gene and protein expression and regulation, and the metabolic output of the system.

Sorghum plants were grown under elevated CO_2 and drought conditions for 120 days during the grain formation and filling phase. Leaf photosynthesis, respiration and stomatal conductance (the rate of CO_2 exchange between leaf stomata and the air) were measured 90 days and 120 days after planting. Plants were harvested at the end of each period, and the biomass and intracellular primary metabolites of leaves, culm, root, prop roots and grains were evaluated. The researchers found that elevated CO_2 reduced stomatal conductance, leading to increased water use efficiency.

"Although minor physiological effects were observed, growing sorghum under high levels of atmospheric CO_2 was found to mitigate the loss of grain quality caused by low humidity during the filling phase thanks to a delay in physiological and metabolic responses to drought," Buckeridge said. "To our knowledge, this is the first study to analyse the simultaneous metabolic responses of the different organs of a plant grown in these conditions. It also shows for the first time how changes in each organ can affect grain composition in sorghum."

The findings pave the way for a deeper understanding of the genes responsible for this resilience to climate change, and in particular of how the plant's organs can interact to improve seed production. "We aim to produce a genetic map that can be used for the purposes of genetic engineering of sorghum and other crops despite the metabolic differences between them," Buckeridge said. "This would help us deal better with climate change in the future, as we would be able to adjust plant metabolism if necessary."

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