Artificial photosynthesis can produce food without sunshine

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Plants are growing in complete darkness in an acetate medium that replaces biological photosynthesis. Credit: Marcus Harland-Dunaway/UCR

Photosynthesis has evolved in plants for millions of years to turn water, carbon dioxide, and the energy from sunlight into plant biomass and the foods we eat. This process, however, is very inefficient, with only about 1% of the energy found in sunlight ending up in the plant. Scientists at UC Riverside and the University of Delaware have found a way to bypass the need for biological photosynthesis altogether and create food independent of sunlight by using artificial photosynthesis.

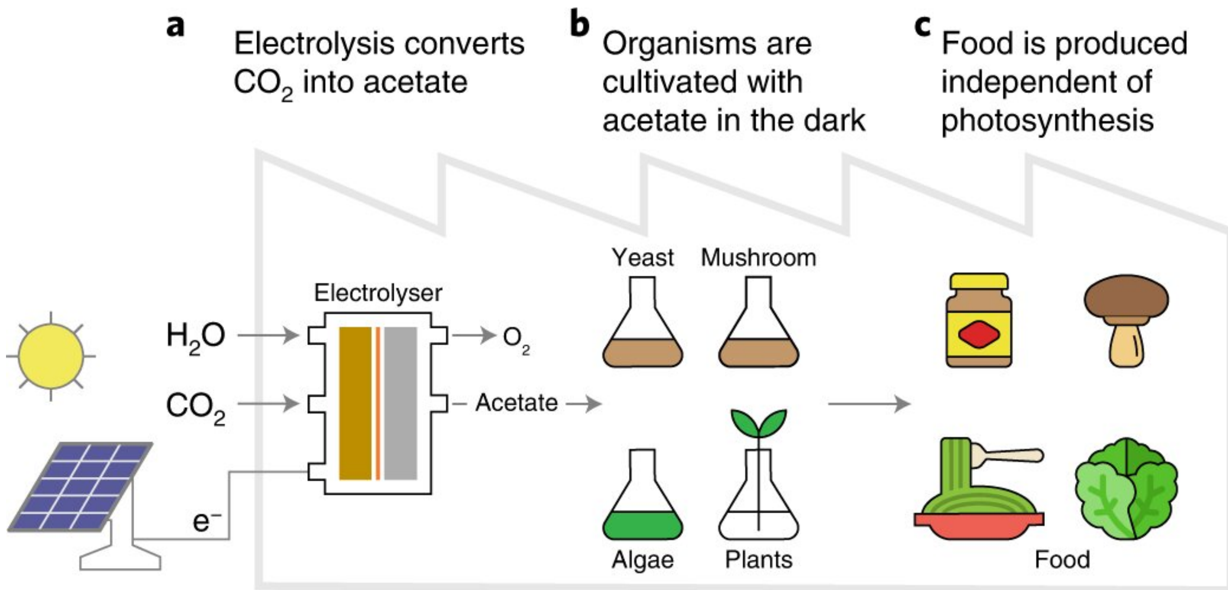
The research, published in *Nature Food*, uses a two-step electrocatalytic process to convert carbon dioxide, electricity, and water into acetate, the form of the main component of vinegar. Food-producing organisms then consume acetate in the dark to grow. Combined with solar panels to generate the electricity to power the electrocatalysis, this hybrid organic-inorganic system could increase the conversion efficiency of sunlight into food, up to 18 times more efficient for some foods.

"With our approach we sought to identify a new way of producing food that could break through the limits normally imposed by biological photosynthesis," said corresponding author Robert Jinkerson, a UC Riverside assistant professor of chemical and environmental engineering.

In order to integrate all the components of the system together, the output of the electrolyzer was optimized to support the growth of food-producing organisms. Electrolyzers are devices that use electricity to convert raw materials like carbon dioxide into useful molecules and products. The amount of acetate produced was increased while the amount of salt used was decreased, resulting in the highest levels of acetate ever produced in an electrolyzer to date.

"Using a state-of-the-art two-step tandem CO_2 electrolysis setup developed in our laboratory, we were able to achieve a high selectivity towards acetate that cannot be accessed through conventional CO_2 electrolysis routes," said corresponding author Feng Jiao at University of Delaware.

Experiments showed that a wide range of food-producing organisms can be grown in the dark directly on the acetate-rich electrolyzer output, including green algae, yeast, and fungal mycelium that produce mushrooms. Producing algae with this technology is approximately fourfold more energy efficient than growing it photosynthetically. Yeast production is about 18-fold more energy efficient than how it is typically cultivated using sugar extracted from corn.



A combined electrochemical–biological system for the production of food from CO_2. **a**, CO_2 electrolysis uses electricity (generated by photovoltaics) to convert CO_2 and H_2O into O_2 and acetate. This process was optimized to produce an effluent output ideal for supporting the growth of food-producing organisms. **b**, *Chlamydomonas*, *Saccharomyces*, mushroom-producing fungus and a variety of vascular crop plants were grown using the electrolyser-produced effluent. **c**, The organisms grown using the electrolyser-produced effluent serve as food or food products. This system is capable of making food independent of photosynthesis, using CO_2, H_2O and solar energy. Credit: *Nature Food* (2022). DOI: 10.1038/s43016-022-00530-x

"We were able to grow food-producing organisms without any contributions from biological photosynthesis. Typically, these organisms are cultivated on sugars derived from plants or inputs derived from petroleum—which is a product of biological photosynthesis that took place millions of years ago. This technology is a more efficient method of turning solar energy into food, as compared to food production that relies on biological photosynthesis," said Elizabeth Hann, a doctoral candidate in the Jinkerson Lab and co-lead author of the study.

The potential for employing this technology to grow crop plants was also investigated. Cowpea, tomato, tobacco, rice, canola, and green pea were all able to utilize carbon from acetate when cultivated in the dark.

"We found that a wide range of crops could take the acetate we provided and build it into the major molecular building blocks an organism needs to grow and thrive. With some breeding and engineering that we are currently working on we might be able to grow crops with acetate as an extra energy source to boost crop yields," said Marcus Harland-Dunaway, a doctoral candidate in the Jinkerson Lab and co-lead author of the study.

By liberating agriculture from complete dependence on the sun, artificial photosynthesis opens the door to countless possibilities for growing food under the increasingly difficult conditions imposed by anthropogenic climate change. Drought, floods, and reduced land availability would be less of a threat to global food security if crops for humans and animals grew in less resource-intensive, controlled environments. Crops could also be grown in cities and other areas currently unsuitable for agriculture, and even provide food for future space explorers.

"Using artificial photosynthesis approaches to produce food could be a paradigm shift for how we feed people. By increasing the efficiency of food production, less land is needed, lessening the impact agriculture has on the environment. And for agriculture in non-traditional environments, like outer space, the increased energy efficiency could help feed more crew members with less inputs," said Jinkerson.

This approach to food production was submitted to NASA's Deep Space Food Challenge where it was a Phase I winner. The Deep Space Food Challenge is an international competition where prizes are awarded to teams to create novel and game-changing food technologies that require minimal inputs and maximize safe, nutritious, and palatable food outputs for long-duration space missions.

"Imagine someday giant vessels growing tomato plants in the dark and on Mars—how much easier would that be for future Martians?" said co-author Martha Orozco-Cárdenas, director of the UC Riverside Plant Transformation Research Center.

More information: Elizabeth C. Hann et al, A hybrid inorganic–biological artificial photosynthesis system for energy-efficient food production, *Nature Food* (2022). DOI: 10.1038/s43016-022-00530-x

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