

A warmer planet, less nutritious plants and ... fewer grasshoppers?

Enlarge / A two-striped grasshopper in Markham, Ontario, Canada.

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It's tough out there for a hungry grasshopper on the Kansas prairie. Oh, there's plenty of grass to eat, but this century's grass isn't what it used to be. It's less nutritious, deficient in minerals like iron, potassium and calcium.

Partly due to that nutrient-deficient diet, there's been a huge decline in grasshopper numbers of late, by about one-third over two decades, according to a 2020 study. The prairie's not hoppin' like it used to – and a major culprit is carbon dioxide, says study author Michael Kaspari, an ecologist at the University of Oklahoma in Norman.

Atmospheric carbon dioxide is at its highest in human history. That's probably fine for plants like the grasses the hoppers munch. They can turn that atmospheric carbon into carbohydrates and build more plants—in fact, plant biologists once thought all that extra carbon dioxide would simply mean better crop yields. But experiments in crops exposed to high carbon dioxide levels indicate that many food plants contain

less of other nutrients than under carbon dioxide concentrations of the past. Several studies find that plants' levels of nitrogen, for example, have fallen, indicating lower plant protein content. And some studies suggest that plants may also be deficient in phosphorus and other trace elements.

The idea that plants grown in today's carbon dioxide-rich era will contain less of certain other elements—a concept Kaspari categorizes as nutrient dilution—has been well-studied in crop plants. Nutrient dilution in natural ecosystems is less-studied, but scientists have observed it happening in several places, from the woods of Europe to the kelp forests off Southern California. Now researchers like Kaspari are starting to examine the knock-on effects—to see whether herbivores that eat those plants, such as grasshoppers and grazing mammals, are affected.

The scant data already present suggest nutrient dilution could cause widespread problems. “I think we are in canary-in-a-coal mine territory,” Kaspari says.

Lower-quality food?

It's clear that rising carbon dioxide levels change plant makeup in a variety of ways. Scientists have done years-long studies in which they pump carbon dioxide over crops to artificially raise their exposure to the gas, then test the plants for nutrient content. One large analysis found that raising carbon dioxide by about 200 parts per million boosted plant mass by about 18 percent, but often reduced levels of nitrogen, protein, zinc and iron.

Vegetables like lettuce and tomatoes may be sweeter and tastier due to added carbon-rich sugars, but lose out on some 10 percent to 20 percent of the protein, nitrate, magnesium, iron and zinc that they have in lower-carbon conditions, according to another large study. On average, plants may lose about 8 percent of their mineral content in conditions of

elevated carbon dioxide. Kaspari likens the effect to trading a nourishing kale salad for a bowl of low-nutrient iceberg lettuce.

When vegetables are grown under elevated levels of carbon dioxide, they typically get bigger and sweeter and may have more of some minerals, such as calcium, an analysis of several different studies found. But quantities of other minerals, including zinc and iron, can go down.

Scientists don't yet know exactly how extra carbon dioxide leads to changes in all these other nutrients. Kaspari, who discussed the importance of micronutrients such as calcium and iron in ecosystems in the 2021 Annual Review of Ecology, Evolution and Systematics, suggests it's a simple issue of ratios: Carbon goes up but everything else stays the same.

Lewis Ziska, a plant physiologist at the Columbia University Mailman School of Public Health in New York City, thinks it's more complicated than just ratios. For example, in the vegetable study, elevated carbon dioxide increased the concentration of certain nutrients, such as calcium, even as

it limited levels of others.

One contributing factor could be plants' little openings, called stomata, through which they take up the carbon dioxide they use to make sugars and the rest of their structures. If there's plenty of carbon dioxide around, they don't need to open the stomata as often, or for as long. That means plants lose less moisture via evaporation from those openings. The result could be less liquid moving up the stem from the roots, and since that liquid carries elements such as metals from soil, less of those trace elements would reach the stems and leaves.

Scientists have also posited that when carbon dioxide is high, plants are less efficient at taking up minerals and other elements because the root molecules that normally pull in these elements are acting at a lower capacity. There are probably multiple processes at play, says Ziska. "It's not a one-size-fits-all mechanism."

Whatever is going on in these well-studied crops, the same thing is presumably occurring in trees and weeds and other non-agricultural species, says Kaspari. "If it's happening to the human food supply, it's happening to everybody else."

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Several studies suggest that Kaspari is right. For example, even though farmers add nitrogen fertilizer to croplands and that nitrogen then washes into neighboring waterways or wildlands, nitrogen availability is on the decline in a variety of non-agricultural ecosystems. In one analysis, researchers examined nitrogen levels in more than 43,000 leaf samples, collected in various studies between 1980 and 2017. Atmospheric carbon dioxide levels rose by nearly 20 percent during that period, and nitrogen concentrations in the leaves decreased by 9 percent. Mineral concentrations are also affected: Scientists who studied trees in Europe between 1992

and 2009 observed a drop in several, including calcium, magnesium, and potassium, in at least some of their leaf samples.

Scientists can also examine museum and herbaria samples to study how plant nutrient content has changed as planetary carbon dioxide levels have risen. Ziska and colleagues did so for goldenrod, a key food source for bees. Using collections from the Smithsonian Institution's natural history museum in Washington, DC, they analyzed pollen from as far back as 1842, just before the American Industrial Revolution. At that time, the carbon dioxide levels were 280 parts per million, compared to just over 420 today.

Pollen protein content, and thus nutrition level, decreased over time by about one-third, the scientists found. Ziska's modern experiments with goldenrod grown under carbon dioxide levels as high as 500 parts per million confirmed that more carbon dioxide yields protein-deficient pollen. Though it's not clear yet what this means for bees, it's probably not good, Ziska says.

The results are striking, particularly compared with crop studies that don't draw on large historical datasets, says Samuel Myers, a principal research scientist at the Harvard T.H. Chan School of Public Health who has investigated the link between the health of pollinators and human nutrition.

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