Curbing toxic metals in spinach and rice crops grown for baby food

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Members of the Seyfferth Lab (Matt Limmer, Angelia Seyfferth, and graduate students Bekah Hanrahand and Frank Linam) harvest rice in the UD RICE Facility. Credit: Monica Moriak/University of Delaware

Rice and spinach are staples for babies' and young children's diets, but toxic metals and metalloids found in those foods can cause severe health impacts.

In particular, heavy metals such as cadmium, lead, mercury, and metalloid arsenic could delay brain development in babies and young children.

In new research published in the academic journal *Environmental Geochemistry and Health*, University of Delaware scientists have found that flooded rice fields tend to contain higher amounts of arsenic and lower amounts of cadmium. The drier those rice fields are, the lower the amounts of arsenic and the higher the amounts of cadmium. However, the higher cadmium is lower than the existing threshold for adverse health effects.

The findings could help establish a course of action for decreasing the levels of these contaminants in foods typically eaten by infants and children. Earlier this year, the U.S. Food and Drug Administration issued draft guidance for the amount of lead allowed in baby foods. It's on the verge of setting new regulations for the threshold of arsenic, cadmium and mercury that can be allowed in infant food as part of its Closer to Zero Action Plan.

Flooding rice fields

Crops such as corn, soybeans and wheat are grown in soils that are not very wet. So farmers water them to make sure the plants get the nutrients they need to grow, but never enough to fully flood them.

In contrast, rice is often grown in very wet, flooded soils. Oxygen that would normally reside in tiny pores in the soil gets lost very quickly and is replaced by water. The limited oxygen shifts the microorganisms in the soil, and those microorganisms start breathing with iron oxide minerals that give the soil a rusty orange color.

"Arsenic likes to stick really tightly onto those iron oxides," said Angelia Seyfferth, a UD soil biogeochemist and professor in the Department of Plant and Soil Sciences, and a co-author of the research. "When the iron oxides are used by these organisms to breathe, they go from a solid mineral to a solution phase. You essentially dissolve them, and when you dissolve them, the arsenic that's stuck onto them goes into the water."

Seyfferth said that once the arsenic is in the water, it can easily be absorbed by the rice roots and transported into the grain.

Seyfferth and research associate Matt Limmer grew rice in 18 small fields on the UD Newark Farm, exposing the rice paddies to different flooded and wet conditions.

"We were hoping to find an optimal irrigation management that minimized both arsenic and cadmium simultaneously," Limmer said, "but we didn't find one in this soil."

Once they harvested the grain and analyzed the amount of arsenic and cadmium in it, the researchers instead found that the more flooded the field, the more arsenic and less cadmium accumulated in the rice. By contrast, the drier the field, the more cadmium and less arsenic accumulated.

"But, even under those drier conditions when there was more cadmium, the concentrations of cadmium in the grain were not of concern for human health," Seyfferth said.

When the rice fields were flooded, and arsenic was taken up, the researchers noticed methanogenesis happening, which is when organisms in the soil produce the potent greenhouse gas methane and emit it into the atmosphere. Meanwhile, the excess water reduced sulfate in the soil to sulfide, causing cadmium to precipitate out with the sulfide.

When they dried the soil out, the researchers decreased the levels of arsenic and methane. Sulfide in the soil was oxidized and became sulfate, which is no longer a solid phase, allowing cadmium to easily filter through and escape into the plant easily.

"By drying out the soil, we're sort of putting the brakes on the microorganisms that breathe with iron oxides and with arsenic," Seyfferth said. "Then we actually increase the amount of cadmium because we oxidize the sulfide to sulfate. When it becomes sulfate, it's no longer a solid phase with the cadmium, and the cadmium can then be free."

Drying the soil out introduced oxygen into the soil pores, Seyfferth said, which slowed down the microorganisms that dissolve iron oxides and create methane and changed the chemistry.

"Once you introduce oxygen, the iron oxides that dissolved are solid again," Seyfferth said. "They're kind of like a Brita filter. The arsenic sticks onto the iron oxides and it's not in the water, so the plant roots can't really get it."

What they found—one metal or metalloid increasing with the other decreasing depending on the level of moisture in the soil—presents a bit of a puzzle.

"There's a challenge," Seyfferth said. "It basically resides in what is this magic number or magic water status in the soil to try to minimize both of them. There really isn't one that is universal across all soils."

Through a U.S. Department of Agriculture National Institute of Food and Agriculture research grant, the researchers are studying arsenic in rice through some field work in Arkansas. They'll work directly with farmers to develop tools to help them manage water flooding their rice paddies.

Meanwhile, the FDA could release new regulations for arsenic and cadmium in infant food by the end of this year, part of its aforementioned Closer to Zero Action Plan. The agency has spent some time researching the effects of arsenic and cadmium and two other toxins, mercury and lead, on child development. The FDA has also been evaluating new technologies or interventions that could stymie exposure to these toxins.

"Our work could hopefully help shape policy," Seyfferth said.

Involving farmers

UD researchers have also reported, in a review paper they published in the journal *GeoHealth*, that producers are willing to take any action needed to reduce levels of metals in their crops, but they need incentives, testing and education in order to do so.

This was the case specifically for the spinach industry in five states—producers, packers, processors, and marketers- whom the researchers interviewed. Spinach can contain amounts of cadmium and lead that it absorbs through the soil.

"It's really important to get stakeholder feedback to see what's feasible for farmers," Seyfferth said, "and that it wouldn't be a big burden to something that they already do, or changing a practice that they're doing, that they have to do to meet some other standard, like a different food safety standard."

The researchers explored interactions between plants with metals and metalloids, comparing and contrasting how cadmium and lead move through the soils and affect leafy greens. They also offer solutions for farmers to decrease the amount of metals and metalloids in the foods they grow.

"Farmers are often working on very thin margins for something like spinach," Seyfferth said. "If the regulatory bodies made it really hard to achieve a certain level of cadmium or lead, they might just switch and grow something else."

Complicating that, one challenge with cadmium in spinach is that water is chlorinated to disinfect spinach. But adding chloride actually makes it easier for cadmium to infiltrate a plant's roots, which translocates it into the leafy green tissues.

"We might be making the cadmium problem worse by using chlorinated irrigation water for leafy greens," Seyfferth said. "Maybe we should think about alternative ways to disinfect irrigation water that doesn't involve chloride."

Seyfferth said one solution to help decrease the levels of toxic metals and metalloids in foods is offering subsidies to farmers to use certain strategies to reduce those levels on their own. Cadmium, which can build up in spinach leaves, could be reduced by making soils less acidic and washing spinach leaves after harvest. Lead is harder to remove, but washing spinach leaves with lemon juice extract could remove up to 26% of the lead in the leaves, the researchers say.

"The solutions are not a blanket solution," Seyfferth said. "They're not for all soils. They would have to be really site-specific."

Limmer and Seyfferth said more research is needed to find an optimal irrigation strategy that lowers levels of both arsenic and cadmium in rice.

"Similar experiments need to be done in a variety of soils," Limmer said, "ideally under different field conditions."

As the U.S. waits for the FDA's draft regulations on the allowable threshold of arsenic, cadmium and mercury in baby food, Seyfferth said she would like to see the federal government redo a study last done in the 1980s. The FDA, U.S. Department of Agriculture and the U.S. Environmental Protection Agency analyzed paired soils and plants in agricultural fields across the U.S. to get an idea of the concentration of metals and metalloids in those plants and soils.

"Since then, there's a lot more spinach being grown now and being grown in areas where it wasn't grown before," Seyfferth said. "Some of those soils are much higher in cadmium. My push would be to redo this survey."

More information: Matt A. Limmer et al, Controlling exposure to As and Cd from rice via irrigation management, *Environmental Geochemistry and Health* (2024). DOI: 10.1007/s10653-024-02116-x

Angelia L. Seyfferth et al, Mitigating Toxic Metal Exposure Through Leafy Greens: A Comprehensive Review Contrasting Cadmium and Lead in Spinach, *GeoHealth* (2024). DOI: 10.1029/2024GH001081

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