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Democracy Dies in Darkness

CLIMATE COACH

The plant protein that could push meat off your plate

Advice by Michael J. Coren
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Duckweed at the Plantible Foods aqua farm in San Marcos, Calif. (Eric Thayer/for The Washington Post)

SAN MARCOS, Calif. — I came to this aquatic farm an hour outside of San Diego because I wanted to see what could be the future of humanity's protein supply.

At the moment, it looks more like a meth lab out of the drama "Breaking Bad," jokes Tony Martens Fekini, the chief executive of Plantible Foods.

Decrepit recreational vehicles squat on the property. In one corner, people tend to vials, grow lights and centrifuges in a trailer lab. More than a dozen big ponds filled with duckweed, a tiny green plant, bask in the Southern California sunshine.

But the only thing cooking here is protein.

[*Want to know how your actions can help make a difference for our planet? Sign up for the Climate Coach newsletter, in your inbox every Tuesday and Thursday.*]

Plantible grows duckweed in ponds housed in greenhouses. (Eric Thayer/for The Washington Post)

Debris from a machine that grinds duckweed. (Eric Thayer/for The Washington Post)

A lemna pond at the Plantible Foods aqua farm. Rubisco is the world's most abundant protein. (Eric Thayer/for The Washington Post)

Within each tiny floating aquatic plant is a molecule colloquially called rubisco. Without it, most life on Earth would cease to exist.

Plants use rubisco protein — technically known as Ribulose-1,5-bisphosphate carboxylase/oxygenase — as the catalyst for photosynthesis, combining CO_2 from the air with the building blocks for sugars and carbohydrates composing the base of our food chain.

Rubisco is arguably the most abundant protein on the planet. Every green leaf has it. But this tireless molecule is locked inside plants' cells, spoiling almost as soon as it comes into contact with the outside world. At the moment, eating salads is the only way to consume much of it.

Plantible's co-Founder Tony Martens Fekini. (Eric Thayer/for The Washington Post)

But Plantible's farm may change that. If it succeeds, duckweed may become humanity's first new major crop in more than a century, a skeleton key to unlock how plants replace animal protein on an unprecedented scale.

Rubisco doesn't just provide the protein we crave. It's one of the world's most versatile proteins, shape-shifting into forms resembling egg whites, meat, milk, gluten or even steak — all extracted from leaves. If we can harvest enough, it may elevate plants from a side dish to the main course — and as I found, it tasted delicious.

Let's dig in.

Protein problem

The world grows more than enough food to feed everyone on Earth. Much of it goes to livestock. About half of the corn and soybeans grown in the United States are fed to cows, pigs and chickens to support meat-rich diets.

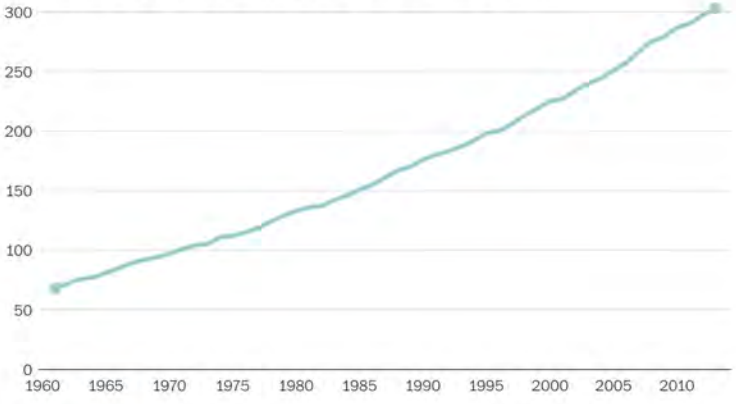
This is not changing anytime soon. Even as protein alternatives proliferate, global meat consumption reached a record high in 2021, roughly doubling since 1990. The typical American consumed about 260

pounds of meat and 670 pounds of dairy last year, according to government statistics.

Advising people to eat less of it isn't likely to do much. In country after country, as incomes rise, meat consumption follows virtually in lockstep.

Global meat consumption

Includes beef, pig, poultry, sheep, goat and buffalo (million tonnes)



Source: Our World in Data MICHAEL J. COREN / THE WASHINGTON POST

That comes at a steep cost to ecosystems and the climate. Meat, at least how most of it is raised today, is the driver behind 57 percent of all food production emissions. The Stockholm Environment Institute estimates current livestock production methods make it virtually impossible to prevent global warming from rising 1.5 degrees Celsius above preindustrial levels, and difficult to avoid a 2-degree increase.

The challenge, then, is not to persuade people to eat more vegetables. It's how to make plant proteins taste better than their animal counterparts.

For a moment, it seemed like "alternative meat" might succeed. Highfliers like Impossible Foods and Beyond Meat, after seeing sales soar in 2020, have faltered. Retail sales of alt-meat dropped more than 10 percent in 2022 amid health questions and high prices. Plant-based milk, while stealing market share from traditional dairy, still accounts for just 9 percent of the volume sold in the United States. Dreams of dethroning Big Meat are out, at least for now.

Daily sources of dietary protein, 2020 average

Source: Our World in Data MICHAEL J. COREN / THE WASHINGTON POST

The problem, in part, is known to anyone who has stirred protein powder into a smoothie, eaten a vegan brownie or bitten into an Impossible burger. Plant proteins aren't a perfect substitute. They can impart grainy textures, 'vegetal' off-flavors or fall short of the savory appeal of eggs, dairy and meat.

So food producers are searching for the holy grail of plant proteins, one that combines the best of plant and animal proteins: affordable, abundant and easy to grow, with the physical properties that make a hamburger or milkshake so alluring.

Rubisco might just be it.

Rubisco: The 'ideal' protein?

For more than 200 years, we've known leaves contain the protein. But rubisco's most remarkable qualities have only come to light through modern science.

Rubisco's composition is a nearly "ideal" protein for humans, according to the U.N. Food and Agriculture Organization, boasting an amino acids profile rivaling egg whites or casein in milk. Unlike the most common plant protein in soy, wheat and peas, it offers a non-allergenic, easily digestible and complete set of all nine essential amino acids our body can't produce on its own.

In contrast to alt-meats, rubisco is a versatile shape-shifter on the human palate. Thanks to its molecular structure, it can bind, emulsify, foam or gel. In baked goods, the protein mimics the luscious mouthfeel of butter and eggs, or the springy bounce of gluten. As a binder in plant-based meats, it retains the delicious bite of a juicy burger. In a fluffy omelet or whipped meringue, it replicates the function of eggs.

"Rubisco does live up to a lot of the hype," says Grant Pearce, a protein chemistry researcher at the University of Canterbury in New Zealand.

Duckweed, in a paste form. (Eric Thayer/for The Washington Post)

The Plantible Foods pilot plant. (Eric Thayer/for The Washington Post)

Matt Mcauliffe, junior mechanical engineer, and Gene Wang, plant scientist, monitor a duckweed grow pond. (Eric Thayer/for The Washington Post)

The problem, however, has been getting it out of the leaf. As soon as a leaf is cut, its compounds bind to rubisco, rendering it unusable as a food ingredient. At the industrial scale, harvesting rubisco has proved to be a formidable challenge.

"You just have to process the plant material reasonably quickly so you don't end up with a brown sludge," says Pearce. Sugar beet leaves, cauliflower, kale, broccoli stems, radishes and even invasive plant species have all been harvested as protein sources. None proved economical.

And some are skeptical it will ever be.

"It's just economics," says Arnold Bloom, a professor of plant sciences at the University of California at Davis. Even at high concentrations, such as in spinach, rubisco represents just a tiny percentage of the plant's biomass. Harvesting it efficiently is a tall order. Its role as a major protein source, he predicts, will be "negligible."

But for Fekini, a former agricultural commodities trader, all roads led to a neglected little plant most people associate with pond scum.

Duckweed is the world's smallest flowering plant. (Eric Thayer/for The Washington Post)

A duckweed factory

"It's a literal weed," says Fekini, 34, as we stare at the minuscule green plants swirling at our feet.

Duckweed, or lemna, doesn't get much respect in most of the world.

While eaten in parts of Southeast Asia, the pond vegetation is regarded as a nuisance elsewhere. That reputation belies the plant's remarkable biology.

The family's 35 or so species thrive on nearly every continent, surviving at near-freezing temperatures in water conditions lethal to many others. As the world's smallest known flowering plant, it consists of a single floating leaf, an oval not much larger than the tip of a pen. Its delicate roots dangle millimeters below the surface. In ideal conditions, it grows at a ferocious rate, doubling in mass every two or three days.

"Everyone who learns about lemna, there is a special place in their heart," says Patrick Shih, a plant bioengineering expert at UC-Berkeley. "There's nothing like it."

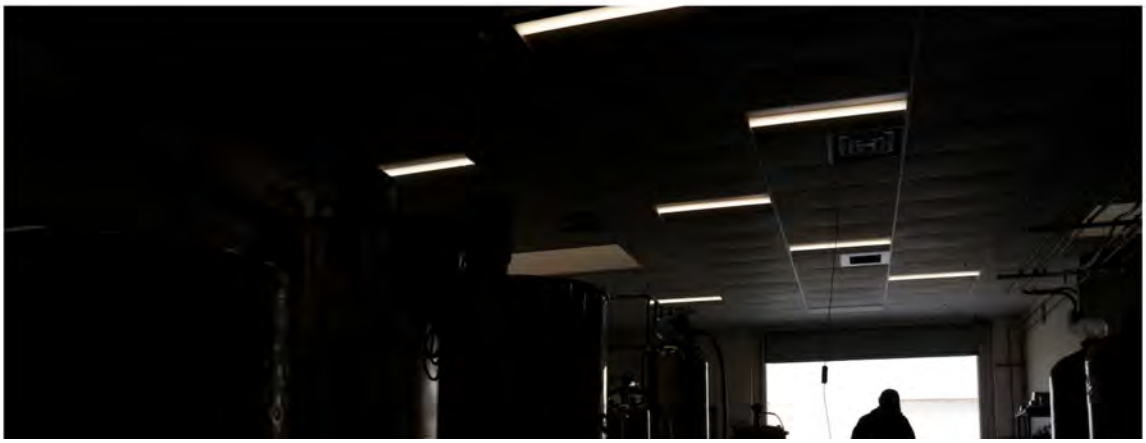
That's what inspired Fekini and his co-founder Maurits van de Ven to transport about 100 duckweed strains to Plantible's R&D laboratory in California. Here, workers test different varieties and select the most promising strains. They tweak the environmental conditions, sample rubisco concentrations and pick the winners. Then the process begins again.

It's what terrestrial farmers have been doing for millennia, a process that traditionally takes years, if not decades, to refine. Lemna's prodigious growth means strains can be selected and improved in weeks.

"We're really trying to create version 2.0 of agriculture," says Fekini. "We need to develop better tool kits, and the only way is to start from scratch, create better ingredients and tap into novel plants. But it's definitely not the easiest route."

Duckweed is separated into a liquid at Plantible's facility. (Eric Thayer/for The Washington Post)

A duckweed grow pond. (Eric Thayer/for The Washington Post)



Plantible's small prototype farm in Southern California is harvesting duckweed, a tiny aquatic pond plant, that promises to make rubisco the next sustainable source of protein. (Eric Thayer/for The Washington Post)

If he succeeds, duckweed may be one of humanity's first new major crops in more than a century, since soybeans introduced from China spread globally during the 1900s. Today, just four crops — wheat, rice, corn and soybeans — supply two-thirds of human calories.

With global warming promising punishing conditions for today's crops, the world needs a new, resilient option to protect the food supply against shocks, says Shih. "To jump to another species that hasn't even been domesticated, you open the door to a whole new design space that is intrinsically different than row crops," he says. "But scaling this up is one of the hardest things to do."

Scaling it up

As we stand in the humid greenhouse in Southern California, a lazy river of duckweed floats past. This is Plantible's pilot farm: more than a dozen cement ponds, each covered with a luxuriant mat of lemna. Whooshing pumps and a paddle wheel keep the water flowing. Greenhouses keep temperatures balmy. Machinery sits ready to harvest the duckweed.

I note it's all a rather low-tech way to grow the future of protein. That's by design, counters Fekini. "Our philosophy has always been finding that balance," he says. "Agriculture is generally low-tech because low-tech is highly scalable and very affordable."

To make rubisco in meaningful quantities, Plantible will need to extract it more efficiently than ever before.

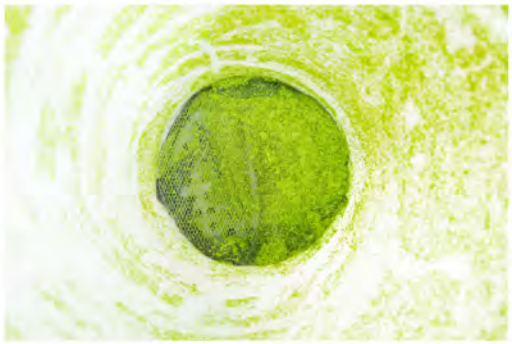
The challenge is that while rubisco is abundant globally, the molecule only represents about 1 percent of a leaf by weight. That means processing enormous amounts of biomass to obtain a relatively small amount of protein. Pearce, at the University of Canterbury, estimates 1 metric ton of leaves yields about 11 pounds (5 kilograms) of rubisco, at least on land. If you're competing against animal protein selling for

about $5 per pound, on average, it's difficult to turn a profit.

But Plantible, backed by Kellogg's, among other investors, says it has two advantages. The first is productivity. Unlike a field, lemna can grow happily in a few inches of water, year-round, in environments perfectly calibrated to maximize growth. Almost all the water is reclaimed during harvest, and fertilizer demands are modest. Scale also works in its favor.

Machinery turns rubisco contained in duckweed into a paste for cooking. (Eric Thayer/for The Washington Post)

After being separated into a liquid form, duckweed is put into a vial. (Eric Thayer/for The Washington Post)



Duckweed remnants in a drum used to transport the plant from a grow pond to a grinder. (Eric Thayer/for The Washington Post)

Plantible's new Texas facility, an old Black Angus cattle ranch, is 50 times larger than its California site. Fekini estimates ponds on the 100-acre site can produce 36 metric dry tons per hectare — roughly 10 times more than soy.

Plantible's other advantage, it argues, is the company's ability to do everything under one roof, from selecting the plants to processing rubisco. By managing every step, it claims it can turn duckweed into protein with unprecedented efficiency.

That has yet to be proved. But in May, I watched a pond full of lemna turn into a white powder ready for baked goods within a few hours. The

plants were harvested and macerated, producing the equivalent of a green smoothie. The slurry was spun in a massive centrifuge, leaving a bright green juice with the aroma of a freshly cut lawn. The rubisco was dried and stored.

At the end of the process, I was handed a bag of fine white powder, almost like flour that I was promised would make delicious cookies.

How does it taste?

When I stirred rubisco into a glass of water, it tasted like nothing at all. The powder dissolved completely, leaving it only slightly more viscous than before. As an industrial food ingredient, that's the point. The colorless, flavorless all-purpose protein can serve specific needs depending on who's using it.

For now, Plantible is marketing a replacement for eggs in industrial baking. It will show up in macarons by Sweet Maresa's starting next month. The New York bakery will later roll other baked goods, like muffins, cakes and cookies, made with Plantible's rubisco.

Since most consumer packaged goods companies are trying to remove expensive, unreliable ingredients — eggs have seen repeated shortages and price spikes — Plantible is positioning rubisco as a superior substitute for dairy and eggs.

Duckweed samples removed from a grow pond sit in a lab. (Eric Thayer/for The Washington Post)

Dried duckweed at a Plantible lab. (Eric Thayer/for The Washington Post)

Brock Kuhlman, a food scientist and chef, works on a rubisco-based cooking paste. (Eric Thayer/for The Washington Post)

Its second product targets alt-meat manufacturers. Since it binds with fats and oils, the protein can produce a plant-based burger that cooks, tastes and feels closer to the real thing without fats leaking out of the patty. Plantible says it has already begun experimenting with rubisco in plant-based sausages, chicken, fish and even steak.

The money to commercialize rubisco is pouring in. Pearce estimates that more was spent last year on developing rubisco than in the previous 20 years combined.

If it works, the photosynthetic molecule may succeed where other alt-meats have faltered, unlocking the market potential of other plant proteins like soy, peas and other legumes, by making them more palatable for people who prefer eating meat.

For that to happen, rubisco's promoters must pass the most difficult test: Your taste buds.

Brock Kuhlman, a trained chef who also holds a Ph.D. in food chemistry, sweeps out of Plantible's test kitchen carrying a platter piled high with baked goods. As a crowd gathered in Plantible's R&D facility, the company's senior food scientist whipped up an array of chewy chocolate chip cookies, pound cake and peaky macaroons, still warm from the oven.

Instead of eggs and butter, Kuhlman says, each one was prepared with rubisco. They look moist and delectable. I bite into one, and then another. After savoring all of them, I search my palate for something missing. I can't find it. The experience of each bite replicates the rich, soft springiness of the best baked goods.

I mention I'm surprised they're so hard to resist.

"No one will sacrifice their taste buds to save the planet," says Fekini as we clear the plate, leaving only crumbs. "It's all about taste. People aren't compromising on taste because of the cool technology behind it. Consumers are ruthless."

Plantible's duckweed-based cooking powder can be used to make cookies and other baked goods. (Eric Thayer/for The Washington Post)

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Michael is a journalist writing the "Climate Coach" advice column for The Washington Post. Before joining the Post in 2022, he spent nearly two decades as a reporter and editor covering climate, technology, and economics for outlets such as Quartz and CNN.com. He was also the managing editor of Cambodia's Phnom Penh Post. Twitter

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