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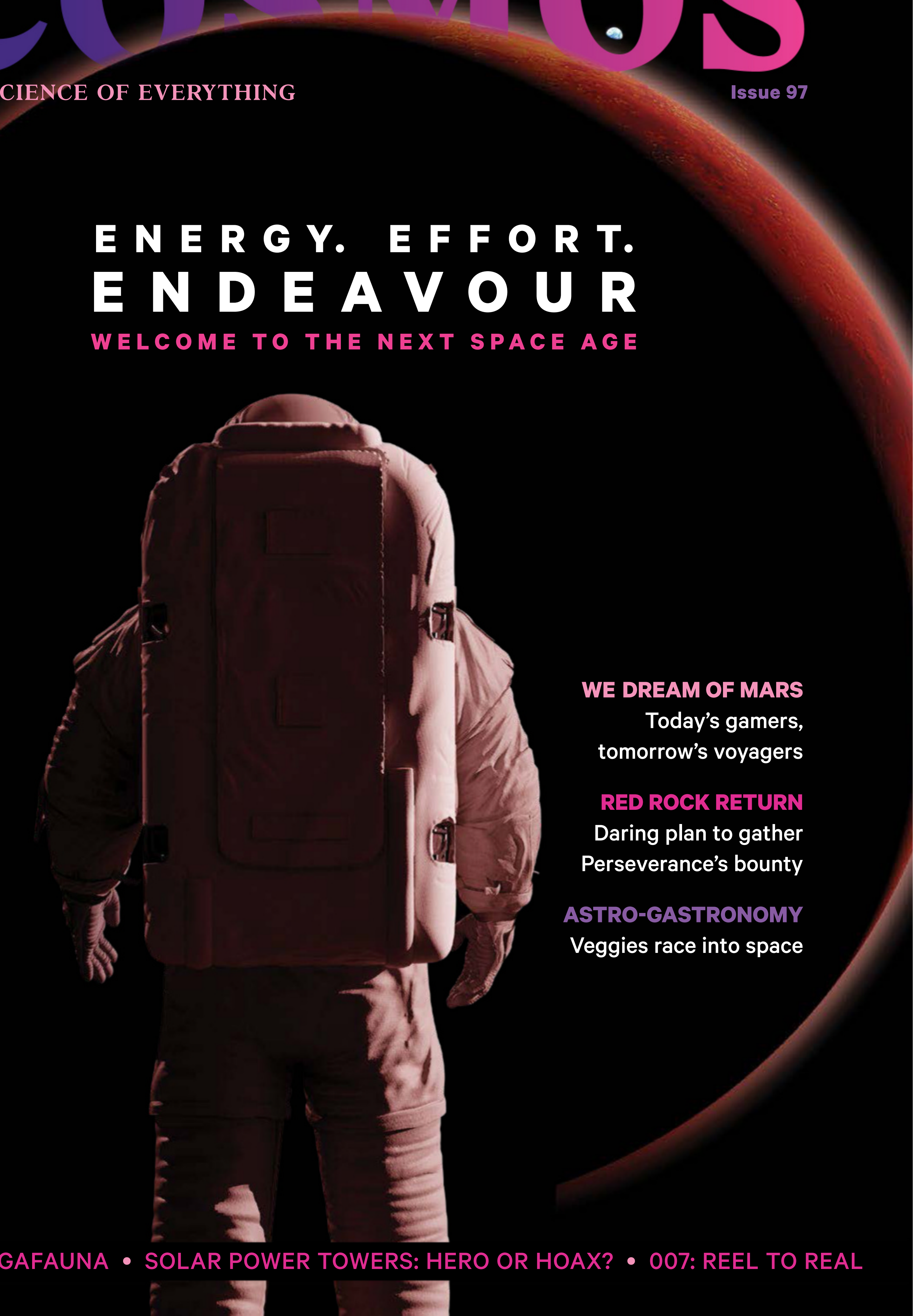

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CRAVED IN SPACE

Almost stranger than fiction: an Adelaide pond weed may pay its own way to Mars, writes **JAMIE SEIDEL**.

Man cannot live on bread alone. Nor woman chocolate. But nobody can survive without bacon. And that's a problem for life in space.

A crisp crunch. A fresh tang. The bite of spice. These are the things astronauts aboard the International Space Station (ISS) quickly come to crave.

Sustenance, it turns out, isn't enough for survival.

Little wonder the most-commonly requested delivery item in space is a crisp, crunchy apple. Or a zingy sausage.

"Eating is a whole sensory experience," says Associate Professor Jenny Mortimer, from the University of Adelaide's School of Agriculture, Food and Wine. "It's about flavours and textures, smells and temperatures." It's also inherently social.

"Meals are something that brings people together," Mortimer says. "Astronauts have been known to take plants out of their research containers and fasten them to the tables where they sit together – there's a real cultural and ritual thing going on there." Plants will help you breathe. They will keep you sane. But, mostly, they will feed you.

"We talk about people going to Mars but we've got a lot of work to do before we get there," says Australian National University Associate Professor Caitlin Byrt. "We need to be able to grow things both in space and in facilities on the lunar and Mars surfaces. The know-how for that doesn't exist yet."

Put simply: we can't meet the nutritional needs of a long-duration space mission – let alone service the emotional associations with food – with just tins, vacuum packs and protein paste.

Livestock is out of the question. And our crops, like the humans that tend them, didn't evolve to live in zero gravity.

In November, the Australian Research Council (ARC) granted $35 million over seven years to establish a new Centre for Excellence in Plants for Space (P4S). Including money from other partners, this brings the total investment in P4S to $90 million.

Eventually, some 400 researchers across Australia will strive to give potential space-faring plants "the right stuff".

Mortimer already has a contender.

It can cope with the cold. It dismisses drought. And when the going's good, it grows very fast.

That's why the descendants of a weed growing in an ornamental pond at Adelaide University's Waite Research Institute could end up on Mars.

LEFT: GREG BARTON / MIDJOURNEY. DUCKWEEDS: IAIN SARJEANT / GETTY IMAGES

Space for life

Astronaut Scott Kelly fell ill in orbit aboard the ISS. His body was struggling to adapt. It turned out flowers were the best medicine.

"They sent zinnia flowers to the space station for no other reason than they were pretty," says Mortimer. "[Kelly] got massively invested in the survival of these flowers. He used to wipe them down each day to try and decontaminate them. Just the psychological thing of having this beautiful flower to take care of made his trip for him."

Then there's the phenomenon of menu fatigue. We all know the feeling. We can get tired of even a favourite food after having too much of it too often. Astronauts are prime candidates for menu fatigue. They eat everything they're given. And they're given meals carefully designed to provide everything they need. But they still end up losing weight.

"It's all just a bit 'brown'," says Mortimer. "They just love having something fresh. They had a chilli-growing challenge recently and they all ate space tacos. And they talk about it as being the best food they've ever eaten."

So, for future space travel, plants can supplement raw nutrition with the vital spice of life.

"But upon arrival at the Moon or Mars, we would need to get to the point of meeting calorie demand," Mortimer adds.

That needs industrial-scale production. And industrial-strength plants.

The right stuff

It costs a ballpark $2400 to put one kilogram of anything into low-Earth orbit. That blows out to about $470,000 for the Moon. And getting it onto the lunar surface is an estimated $1.9 million.

That's why doing more with less is a matter of life or death.

Plants can't afford to be passengers. They must be continually productive. They must be compact. (This won't mean the return of the square watermelon.)

"They've got that long period of growth where you're not getting any harvest at all," Mortimer explains. "You've got to calculate very carefully how much plant takes up how much space to produce how many calories per person, because you can't afford to run out."

That makes strawberries prime contenders. And carrots.

"Everyone likes them," Mortimer explains. "Not only are they nutritious, they're also delicious and colourful." They're also very efficient: You can eat the leaves. And that meets the "zero waste" mantra dominating every aspect of life in space.

So astrobiologists are seeking the perfect 'template' plant. One that meets most of the criteria for life in space, but that can also be adapted to provide the rest.

"I'm biased in that I have a favourite plant already," Mortimer says. "It's called duckweed. It's fantastic, because it's basically flat, and you can eat the whole thing."

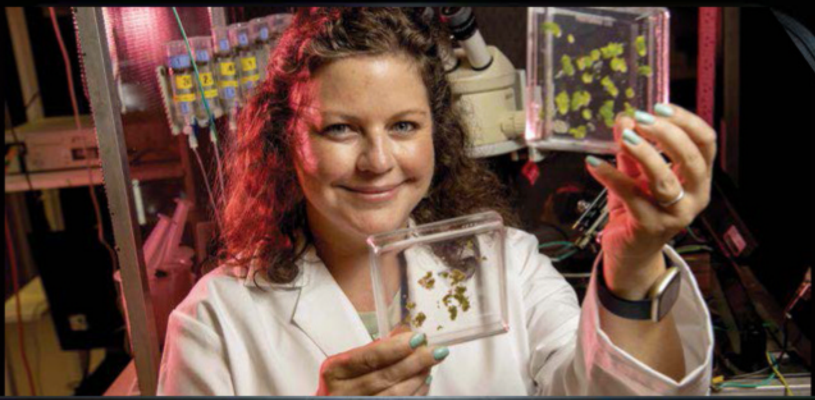
The fast-growing green leafy vegetable – Lemnoideae subfamily – floats on a very thin layer of water. And it's been part of the diet for people in many parts of Asia for millennia.

"It has all the amino acids humans need, starch, fatty acids, pretty much every vitamin apart from B12 and D," says Mortimer. "They say it has three times as much protein as spinach."

But duckweed is up against some stiff competition. Israel's "Space Hummus" project put 28 chickpea seedlings into orbit earlier this year. Lettuce, cabbage and kale have been up there on and off for a while. But Mortimer thinks duckweed has an edge: it tastes like whatever you grow it in.

"DUCKWEED IS WHAT I CALL A CHASSIS FOR ENGINEERING. IT'S THE STARTING POINT. NOW WE JUST HAVE TO FIGURE OUT WHAT WE CAN ADD INTO THAT"

SHIP PORTAL: GUILLAUME / GETTY IMAGES. ABOVE: ESA / ALEXANDER GERST



It's not easy being green: Early plants in the ISS's onboard Vegetable Production System – aka Veggie – experiment were subject to instruction manuals. When the zinnia (above right) started wilting, astronaut Scott Kelly pointed out: "I think if we're going to Mars, and we were growing stuff, we would be responsible for deciding when the stuff needed water. Kind of like in my backyard, I look at it and say 'Oh, maybe I should water the grass today'." Kelly paved the way for more autonomous gardening on the craft, such as (opposite top right) astronaut Serena Auñón-Chancellor's harvest of red Russian kale and dragoon lettuce in 2018, which the crew enjoyed with balsamic vinegar. Associate Professor Jenny Mortimer (above left) thinks that the humble duckweed she's displaying could provide a plentiful and tasty protein source for our first space colonists.

ABOVE: NAOMI JELLICOE PHOTOGRAPHY / NEWSPIX. RIGHT: NASA

"My colleague in the US has grown it in bacon flavour," she quips.

Mmmm. The Homer Simpson dream: unexplained bacon.

Multi-functional flora

"We're going to take a couple of suitable plant species and try and use them to cover as many of our requirements as possible," says Mortimer.

What would such a plant look like? For openers, it's a matter of identifying what properties are necessary, and, further, determining if these already exist in nature.

Then researchers need to work out if these can be bred or designed into just one resilient plant.

"Duckweed is what I call a chassis for engineering," says Mortimer. "It's the starting point. Now we just have to figure out what we can add into that."

Students are working on ways to make it produce vitamin D and improve its vitamin A output. One is looking at growing bioplastic construction materials. Others are trying to get the plant to synthesise pharmaceutical compounds such as aspirin.

Byrt, a biological engineer, says it's highly likely plants can become multipurpose factories – up to a point.

"With duckweed, it's handy you're dealing with something that's already edible," she says.

"There is a range of plant features you may want to take advantage of on space missions. Having a diversity of plants will be an advantage." Some plants have evolved to optimise the production of starch or sugars. Others do oils or fibres.

"You could hypothetically engineer a plant that could switch from one kind of oil to another – such as vegetable fats to Omega 3," Byrt adds.

"With aspirin, for example, it is a chemical that comes from willow bark. So I can't see why you couldn't engineer new plants and reprogram their existing biochemical pathways to produce related chemical products." Ultimately, the idea is to give plants useful "genetic circuits": the ability to switch the production of different compounds on or off according to demand.

"The ISS is only 400 kilometres away, and it's hard enough to treat those astronauts," says Mortimer. The Moon is 384,400km distant. Mars is 100 million km.

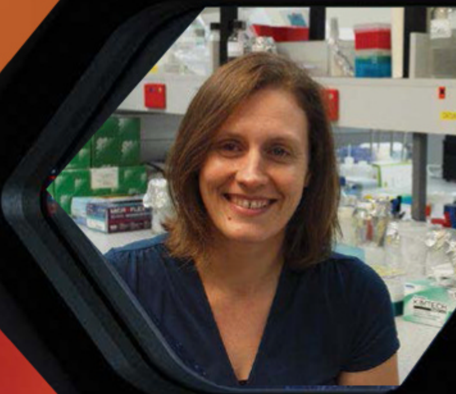
"So you're not going to be able to take a pharmacy with you, or keep it fully stocked," she says. People are also going to be in short supply. And time for maintenance will be scarce.

"We're going to need automation. So, to what extent can we roboticise everything?"

And how much can you squeeze out of every plant?

"We've basically got to track every molecule of carbon, every molecule of water, make sure we know where it's going, where it's coming back," Byrt adds. "The same for every molecule of nitrogen. It focuses your mind on how many resources you are really using – how much energy you're using." It's the ultimate expression of a circular economy.

In space, it's a matter of life and death, Mortimer says, "but it relates back to our agricultural problems on Earth as well: climate change is happening at an alarming rate. And conventional ways of doing things can't keep up."



Germinating knowledge

We've already learnt a lot from two decades of near-permanent life in orbit. "One is that plants are pretty resilient, and things we'd expect to be a problem are not," says Mortimer. "But also that all species don't behave the same way."

How would plants cope not knowing which way was up? Would they, in the absence of gravity, become a tangled ball of roots, leaves and branches?

"It turns out if you provide light from above, most plants go – okay, there's no gravity, but I can still grow towards the light," says Mortimer. "It's not true for all. But it is for most."

Astronauts are pretty much the busiest humans on or off the planet. Researchers only get to book a fraction of their time. And only one of them has been a plant molecular biologist: that's put a limit on the complexity of orbital plant experiments.

"Although we've made a lot of progress, it's still comparatively limited," says Mortimer. "And honestly, a lot of the work up until now has been about more the technology infrastructure than the plants themselves."

Those infrastructure problems are not insignificant. How do you control how water moves in microgravity? Its behaviour is weird: it's globby and sticky. It tends to clump around plant roots – and that convinces the plants they're drowning.

Another issue: how do you balance the plants' atmosphere? They don't like too much carbon dioxide (nor do humans). And CO_2 levels on the ISS are four times higher than what would normally make a person drowsy.

As associate Professor Caitlyn Byrt (above left) points out, plants are "multipurpose factories", providing air filtering and textiles in addition to nutrition. Also morale, as Expedition 65 flight engineers (above, from left) Mark Vande Hei, Shane Kimbrough, Akihiko Hoshide and Megan McArthur, show. They're posing in 2021 with the first chilli peppers grown in space as part of the Plant Habitat-04 investigation – and served in "the best space tacos yet". This year, Expedition 67 astronauts (opposite top left) Jessica Watkins and Bob Hines explored soilless methods of growing plants as part of the XROOTS project.

But plant-informed technology is already solving these problems in space.

Water recycling filters aboard the ISS used to get clogged and degrade. Astronauts got sick from the contaminants that slipped past.

"You could say we're a bit obsessed about a type of membrane protein called aquaporins," says Byrt. "They're in all different kingdoms of life. They have a range of different purposes."

In trees, they help to draw moisture through the root system and into up to 100 metres of trunk and branches – all the while distributing specific nutrients where needed. In human kidneys, they help sift up to 200 litres of blood each day to keep water and mineral levels optimal.

A Danish company – Aquaporin A/S – has now successfully coopted the billions of years of evolutionary improvement that went into aquaporins and translated it into new filtering membranes capable of extracting pure water from urine.

No triffids today

Soil, and the rich microbial life within it, turns out not to be a universal necessity. Some plants can do quite well without it. Others only need an alternative.

"Plants that need a microbiome get something out of it they couldn't get otherwise, like nitrogen or phosphates," says Mortimer. "But if we're already providing all that to them, then – in theory – we can grow all these plants in sterile aseptic conditions."

But space isn't a sterile environment.

One only needs to look at the filmy layer of microbial slime that coats just about everything

FROM LEFT: UNIVERSITY OF ADELAIDE. NASA X 2

aboard the ISS. In just 20 years, it's evolved to be a new species.

And that raises a whole new set of questions.

"Humans will be there, and we're walking Petri-dishes of just about every kind of bug you can imagine," says Mortimer. "So if you've completely cleaned out the microbial population on the plant itself, do you increase the risk of human bacteria adapting itself to take up that space? You've opened up an ecological niche, just as you do when humans take antibiotics."

It's an issue international space agencies are taking seriously. And they're keen to figure it out.

They don't want infestations of weeds on Mars. Nor fields of fungi. "We've learnt from human exploration and colonisation in the past that people make a lot of mistakes," says Mortimer. "So we're going to have to be very cautious."

Branching out

Water is heavy. Soil is heavy. Both are terribly messy, even when not in zero gravity.

That's where science fiction falls down. There won't be giant glass domes spanning vast, green open spaces under the light of 100 billion stars.

Fortunately, hydroponics and aeroponics appear to work well in orbit. That means stacked industrial racks of self-contained arboretum shelves are viable.

Each drawer will be a closed, controlled environment. A tiny fraction of the water you would normally use can be delivered directly to the roots. And this can be primed with whatever nutrients a particular plant needs at any particular time.

"That's why some of the Australian companies that work in this closed environment, agricultural space are interested in collaborating on space projects," says Mortimer. "They can see the very close links between efficiency in space and the effectiveness of vertical farming on Earth."

Early calculations suggest a 2m square by 2.5m high cabinet of tightly packed duckweed could sustain a single person with a full-protein diet.

At first, it may only produce a protein shake. Ultimately, it may simulate meats and cheeses – and manufacture the thread needed to mend a torn shirt.

But much more research is needed. Every aspect needs to be measured and tested, every challenge understood. "At first you do as little as you can get away with so that people can survive," says Mortimer. "Only then can you gradually start to build out into what you ultimately need.

"If you want to colonise the Moon, if you want human exploration of Mars – you're going to need plants. There's no two ways about it." ◉

JAMIE SEIDEL is based in Adelaide. His story on mining rare metals appeared in Issue 96.

RIGHT: DEAGOSTINI / GETTY IMAGES