Australian strawberries join new mission to inhabit space while turbo charging sustainability innovations

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- Strawberry was selected as one of four focus plants to be optimised for space and for greater on-Earth sustainability
- Strawberry has the genetic potential to be an all-around sustainable space plant
- Innovations from space biology will flow to Australian strawberry growers on Earth

It is 2044, a mere 20 years away, and a group of astronauts living on Mars take a break. They reach into the space garden, pick strawberries, and eat them fresh. The taste is sensational – intensely sweet with some tart undertones – engineered to overcome limitations of tastebuds in space.

The space strawberries provide the engineers with vitamin C, sugars, and fibre – but most importantly - provide them with a hit of happiness stimulating dopamine and endorphin production in the middle of their brains, giving senses of relaxation, pleasure, beauty, and accomplishment of growing, picking and eating fresh food with their human companions.

With the strawberries, they reach for a cup of strawberry leaf tea, made from "waste" leaves enriched with genes for protein, oils and starches. Natural strawberry flavours are transformed to the leaves, along with other familiar tea molecules.

What a contrast to what astronauts eat today - dried packaged food, and only available in amounts to get them past the moon.

Today in 2024, the Australian Research Council launched a seven-year Centre of Excellence in Plants for Space. Five Australian Universities, led by the University of Adelaide, are partnered with international space and agriculture agencies, including the Australian Space Agency and NASA, to meet the grand challenge of feeding humans in space.

The aim is to create the plants and food to sustain space habitation by humans; at the same time as spinning off technologies and innovations for sustainable food productivity on Earth. Space research is a catalyst for Earth inventions, and until now, has been dominated by physical sciences.

This century will see the biological sciences revolutionised for space. Space habitation will require the ultimate plant-based diet, because only plants can convert sunlight into energy.

Strawberry was selected as one of four focus plants to be optimised for space and for greater on-Earth sustainability. The other three are: Duckweed from *Lemna* or *Wolffia* genera (to be biofactory "workhorse"), Lettuce (for fresh, leafy crunch) and Tomato (for food and existing knowledge about its genetics).

Strawberry contributes unique functions to humans, notably psychological benefits (see box).

Features that make Strawberry an ideal plant for space development

- **Meets human needs.** Strawberry supplies nutritious and psychological needs of humans. Astronauts rank strawberries highly in food tests; and models of future space habitats consider how plants and people will live together (Figure 4A,B).
- **High potential edible index** as leaves and berries can be eaten safely.
- **Low risk of extinction** since strawberry regenerates by seed, runner or tissue propagation.
- **Wide, untapped genetic variation.** Strawberry varieties eaten today come from a narrow genetic base, relative to tomato, for example. Strawberry has wide potential variation from diverse ancestors, modern marker-assisted breeding and new biotechnological approaches such synthetic biology, whereby functions are controlled to turn on or off in specific parts of the plant (e.g. the roots) or at specific times (e.g. flowering window). All these approaches can aid the strawberry space program.
- **High on-Earth demand for innovation in growth and harvesting systems.** Strawberry for space will be bred for soilless systems, without soil fumigation, and with ultra-efficient use of recycled water and nutrients by salt-tolerant, minimal root systems. Fruit and leaves will be picked by hand and machines. These space innovations are required to increase on Earth sustainability and productivity.

Figure 1. Scientists visiting VSICA in Toolangi to plan key traits for space strawberries. Photo credit: Angela Atkinson

From a biotechnology point of view, strawberry is an emerging crop with a sound basis for genetic improvement. The gene codes of the widely grown garden strawberry (*Fragaria x ananassa hybrid octoploid*) and the ancestor alpine strawberry (*Fragaria vesca diploid*) are sequenced. Both types can be "transformed", by inserting a gene or editing a gene using tissue culture to make modified strawberry plants. The breeding cycle is short because of runner propagation and selection by gene markers or trait phenotypes.

Last year, researchers began scoping traits required for space and on-Earth (Figure 1).

To date, three traits are targeted for improvement:

- Roots adapted to soilless systems
- Greater fruit yield and flavour, at desirable times
- Zero-waste

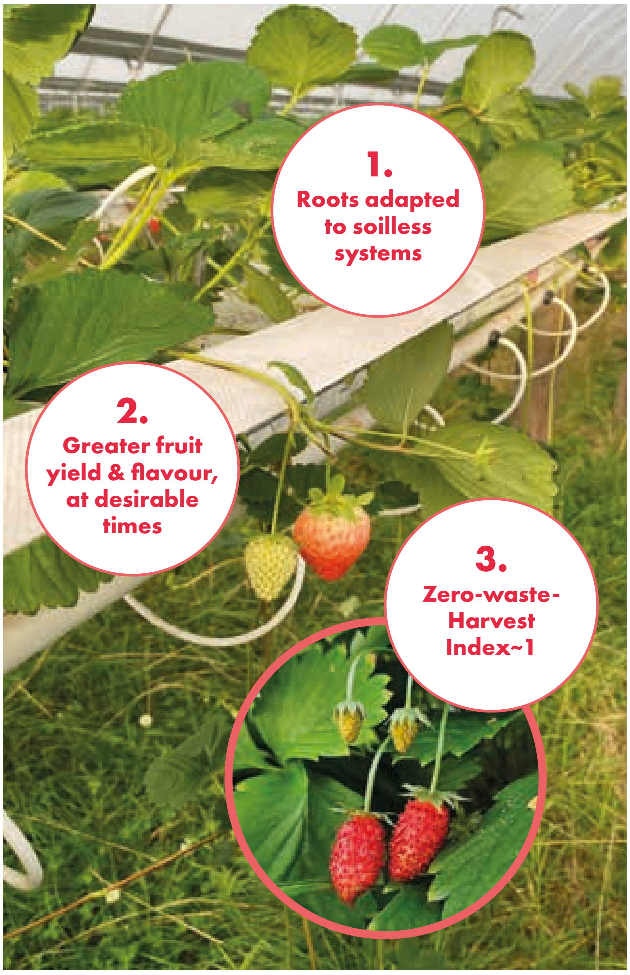

Figure 2. Target traits for strawberries created for space and on Earth. Photo credit: Michelle Watt

1. The initial focus is root system improvement (Figure 3). Most crop improvement has focused on above ground traits; however at least 50% of the plant is in the root systems.

   Root systems of strawberry for soilless systems in space and on Earth need to be smaller but more efficient in water and recycled nutrient uptake (reducing clogging of thin film pipes and reducing waste), tolerant of the salts in hydroponics, and tolerant to wetting (low oxygen) and drying cycles. Initial observations of root system architecture (Figure 3A) suggest wide variation from garden to alpine varieties.

   We recently imported alpine strawberry *F. vesca cv.* Hawaii 4 from the USA to Victoria (University of Melbourne) (Figure 3B). This genotype grows well in tissue culture (Figure 3C), enabling insertion of genes for root and other plant improvement. We will alter genes in roots to make smaller, more efficient and salt and air tolerant roots. These genes are currently being tested and visualised in the model plant Arabidopsis (Figure 3D).

2. Greater, more flavoursome fruit yield can come from greater allocation of biomass and sugars to fruit, also increasing harvest index. It could also come from fruiting earlier and later during the strawberry life, providing growers on Earth with varieties that are neutral to daylength. Space conditions reduce taste, and an ultra-intense flavour is desired. Opportunities to intensify flavour may come from alpine strawberry ancestors (inset of Figure 2).

3. Zero-waste, or "complete-use" means all plant parts meet a need and maximises conversion of water, nutrients and energy resources to food. Today on Earth, leaves and stems are wasted. Strawberry has a relatively low harvest index of 0.3 (proportion of commercial fruit yield to total above-ground biomass) compared to, for example, tomato at 0.7.

   One way to increase the harvest index is to find ways by which leaves or leaf-products can be eaten, therefore a target is enhanced leaf flavour and nutrition and conversion of leaves into an additional product on Earth.

   Research to select or develop the best fruit plants for Space is ongoing in NASA (Figure 4C) and will be supported by research in the Australian Centre of Excellence in Plants for Space.

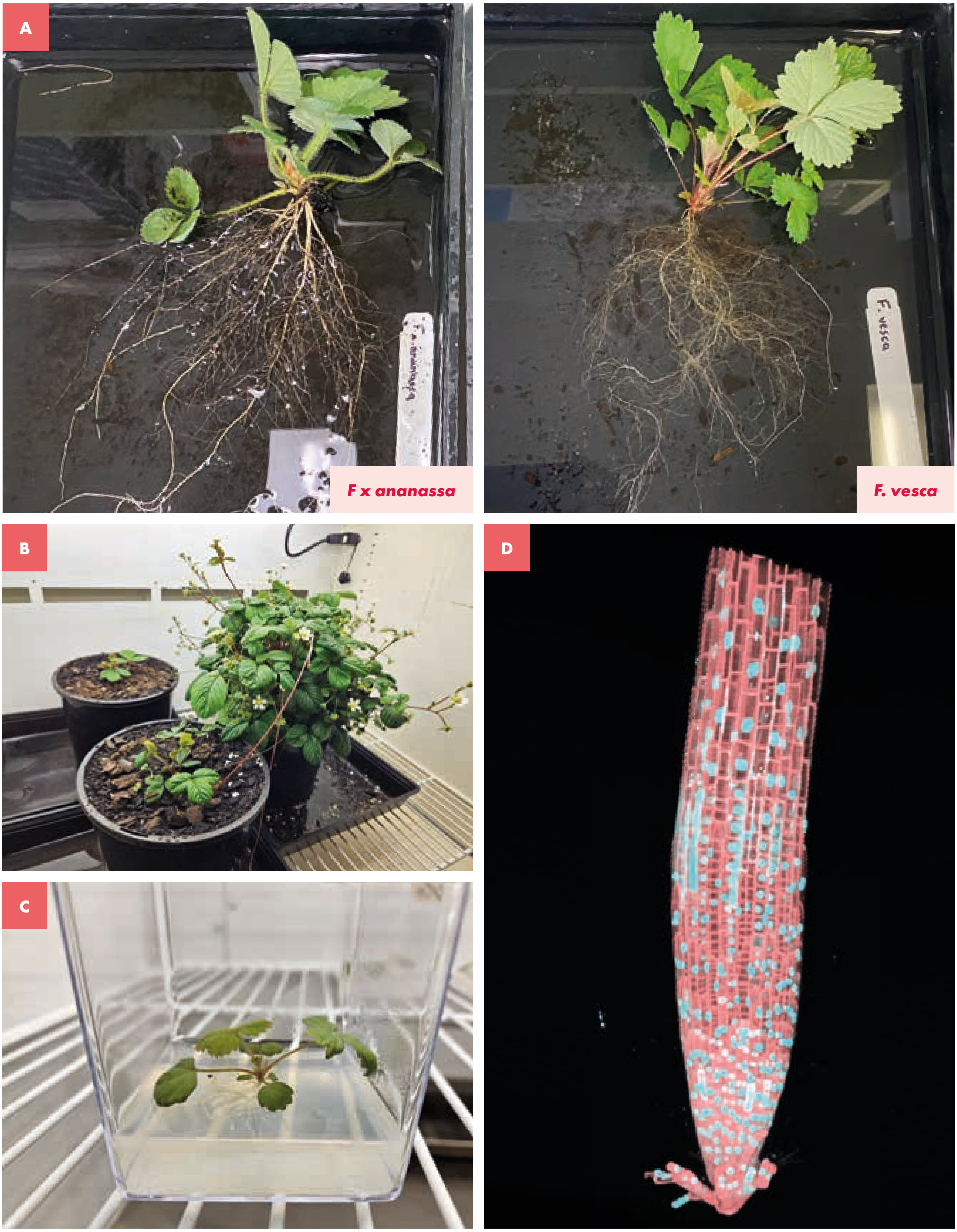

Figure 3. Root systems of strawberry need to be optimised for space and Earth

A. Wide genetic variation exists for root system size, length and fineness
B. *F. vesca* Hawaii 4 is a genetic model for gene discovery and manipulation outside breeding.
   Seed was sourced from the USA and is growing at the University of Melbourne
C. Hawaii 4 grows in tissue culture for future insertion of genes
D. Root specific genes have been visualised in *Arabidopsis*, and these genes are candidates for strawberry root system improvement

Photo credits: A. Michelle Watt; B-D. Jacob Calabria

Figure 4. Models of space habitats for plants and research on the best varieties of plants for space

A. Plants in a model of the Sierra Space Life Habitat showing zones for growing plants and living alongside each other
B. Life-sized model of the Lockheed Martin Deep Space Habitat with chambers for inverted plant growth
C. Test crop species being evaluated for space missions at NASA Kennedy Space Centre. Plants are grown under low power LED lights, their features measured, and the nutrition and quality of fruits are tested. The Sierra Space Life Habitat and Lockheed Martin Deep Space Habitat models are on display at Kennedy Space Centre Visitor Complex

Photo credits: Harvey Millar during visit to NASA Kennedy Space Centre August 2023

On Earth, the strawberry industry faces major challenges from environmental compliance laws related to the use of fumigants and plastics, and from variable climate.

At the same time, demand for strawberries is growing nationally https://www.abc.net.au/news/rural/2021-09-27/blueberry-vs-strawberry-australias-most-valuable-berry-crop/100493978 and internationally https://ukuat.org/2021/07/22/what-is-the-role-of-tcea-in-the-worldwide-strawberry-production

We are optimistic that strawberry has the genetic potential to be an all-around sustainable space plant, and that innovations from space biology will flow to Australian strawberry growers.

Acknowledgements

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The Centre is keen to interact with growers and industry across the Australian sector, to add and refine improvements.

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