Advanced Research + Invention Agency ARIA

Programmable Plants

Opportunity space

v1.0

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CONTEXT

This document describes an opportunity space - an area that we believe is likely to yield breakthroughs, from which one or more funding programmes will emerge.

In tandem, our programme hypothesis related to this opportunity space has now been published. You can read this document **here**. [PDF]

This opportunity space is not currently soliciting feedback – you can stay up to date with this opportunity space, plus others across ARIA, **here**.

An ARIA opportunity space should be

+ important if true (i.e. could lead to a significant new capability for society),
+ under-explored relative to its potential impact, and
+ ripe for new talent, perspectives, or resources to change what's possible.

SUMMARY

Plants have paved the way for human existence and hold tremendous potential to solve some of our most pressing challenges such as food insecurity, climate change and environmental degradation. Programmable plants can secure our future on earth – providing not just food, but a sustainable and thriving biosphere for future generations.

BELIEFS

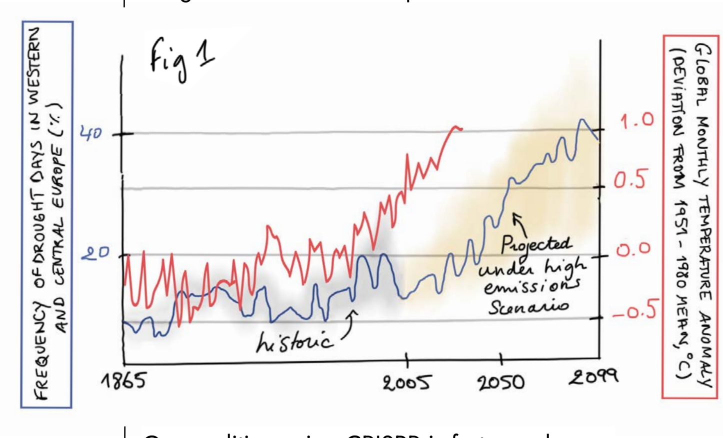
The core beliefs that underpin/bound this area of opportunity.

1. Today's agricultural system is struggling to address the coupled challenges of sustainable food supply and stable climate ⟶ **we need a paradigm shift to accelerate agricultural innovation.**
2. Plants represent 80% of earth's biomass and are rapidly, cost-effectively and widely distributed across our planet ⟶ **plants represent an ideal technological platform to provide low-cost, sustainable resources at scale.**
3. Advances in gene editing and genetic modification are revolutionising our ability to tailor the traits of organisms ⟶ **we can predictably and efficiently develop amazing new plants to provide all of society with abundant and sustainable resources: food, fuel, medicine, shelter and beyond.**

OBSERVATIONS

Some signposts as to why we see this area as important, under-explored, and ripe.

Climate change, especially the uncertainty and severity of extreme weather events, is stressing the global agrifood system. Plant engineering can both mitigate the stress and help address the root cause.



Gene editing using CRISPR is faster and more precise than genetic modification, and increases the predictability of phenotypes ten-fold.

It typically takes eight years to develop a new crop variety in the UK. During the COVID-19 pandemic, we made a vaccine in one year instead of ten.

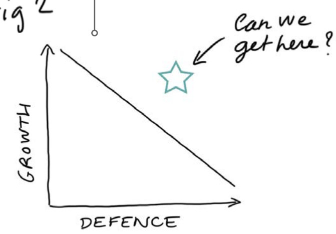
How can we similarly fast-track crop development to stay abreast of our changing climate?

Transformation - the incorporation of new genes into plants - enables us to add and change plant functions. Tissue culture is a major bottleneck that limits transformation speed and transferability between species. The regeneration phase for plant material in tissue culture can take months.

Moving out of tissue culture would be huge!

Crop optimisation has historically been limited by trade-offs between yield and resilience. We know of mechanisms to regulate these trade-offs (e.g. hormonal intervention by fungal endophytes), but how can we overcome them?

Fig 2



In the future we'll design, write and build fully synthetic crop genomes.

De novo pathways and fully synthetic *de novo* organism synthesis including a minimal genome have been proven in bacteria.

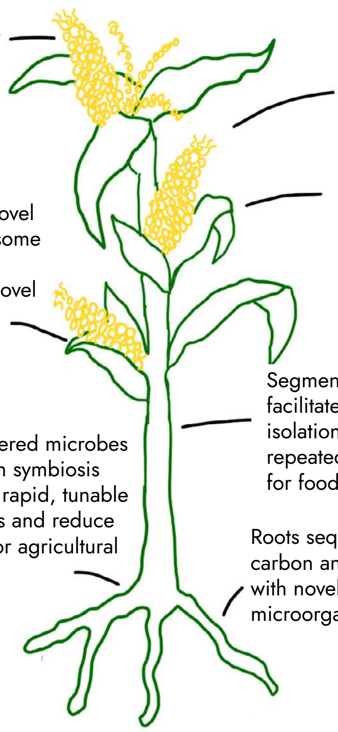
In the short term, we could develop synthetic plant chromosomes and chloroplasts *in vivo* that will transfer gene modules into crops to deliver specific functionalities.

Revolutionising transformation would unlock the power of gene editing, providing major benefits to breeding and research. We need a method that is high-yielding, transferable between species and does not rely on tissue culture.

Fig 4

Possibilities for a programmable plant

TECHNIQUES | TRAITS + APPLICATIONS



Gene editing to improve nutrient composition.

Insertion of novel mini chromosome or plastid for synthesis of novel compounds.

Engineered microbes living in symbiosis deliver rapid, tunable benefits and reduce need for agricultural inputs.

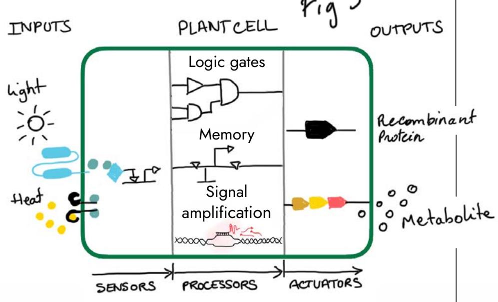
Stable yield of a highly nutritious easy to process, food product.

Leaves contain dosage controlled pharmaceuticals e.g. edible vaccines for livestock.

Segmented stem facilitates hydraulic isolation to allow repeated harvesting for food and biofuels.

Roots sequester carbon and interface with novel beneficial microorganisms.

Fig 3



Emergent possibilities include meristems and pollen targets. Directly editing seeds could be on the horizon!

A transferable transformation method would enable greater use of orphan crops and crop wild relatives to increase diversity and resilience.

For transient in-field adaptations, viral delivery of genetic material can transform crops.

Can we develop a universal transient gene expression method?

AI can guide edits and select transformed plants but we need innovations in method development to streamline design.

Target and network discovery are needed to make synthetic chromosomes and chloroplasts effective in multiple species. Breakthroughs are needed for centromere formation for bottom-up synthetic chromosomes, since centromere formation in plant cells is under epigenetic control.

SOURCES

A compiled, but not exhaustive list of works helping to shape our view and frame the opportunity space (for those who want to dig deeper).

1. UNFAO: The State of Food Security and Nutrition in the World 2023
2. IPCC: Sixth Assessment Report on Climate change
3. The timing of unprecedented hydrological drought under climate change (Figure 1)
4. Climate change impacts data (Figure 1)
5. Feeding the world: improving photosynthetic efficiency for sustainable crop production
6. Global change and vegetation
7. The new frontier of genome engineering with CRISPR
8. Gene editing using TAL effector nucleases
9. Genetic Technology (Precision Breeding) Act 2023
10. Recent advances in crop transformation technologies
11. Advances in delivery mechanisms of CRISPR gene-editing reagents in plants
12. How to build a genome
13. Plant chromosome engineering
14. DNA synthesis technologies to close the gene writing gap
15. First synthetic bacterium
16. Plant gene editing through de novo induction of meristems
17. Organelle-targeted gene delivery in plants by nanomaterials
18. Plant virus-derived vectors for plant genome engineering
19. The design of synthetic gene circuits in plants (Figure 3)
20. Minimising and re-functionalising genomes using synthetic biology

ENGAGE

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