

Final Report

Lean design workshop to understand future challenges for horticulture production in tropical and subtropical regions of Australia

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AS21003

Project:

Lean design workshop to understand future challenges for horticulture production in tropical and subtropical regions of Australia (AS21003)

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Public summary

The Australian horticulture industry has long enjoyed a domestic and international reputation as a sustainable producer of premium safe food—primarily due to our high standards across all supply chain stages, from farm to consumer. There is an imminent need to drive innovations supporting the sector's vibrancy for domestic consumption and international markets. The AS21003 project used a lean design approach to explore the challenges and opportunities that tropical and subtropical horticulture will face over the next 5-10 years and identified the transformational research and development required to ensure the industry's long-term sustainability and global competitiveness. The project identified industry-wide challenges and opportunities through stakeholder engagement activities, including a survey, interviews, and a workshop. The insights from surveys and interviews mainly provided 'horizon 1' type challenges. A workshop was held to focus on transformational opportunities with the stakeholders in tropical and subtropical horticulture.

The participants provided insights on the current and future challenges for horticulture. Adapting to changing climate and climate policy was recognised as massive challenge, including coping with the operational requirements and costs associated with implementing zero net emission technologies. Increasing production costs, the need for automation to meet environmental goals and labour, and reliable market access were highlighted as long-term challenges to maintaining profitable businesses. The requirement for sustainable and alternative cost-effective options on multiple fronts including biosecurity threats and managing pest incursions to reduce challenges from pesticide resistance and MRL breaches and to safeguard market access was highlighted.

A summary of the transformational opportunities identified across regions and tropical and subtropical crops include:

1. **Implement climate-resilient production systems** (controlled environments and outdoors) to enable growers to meet the demands of climate change.
2. **Harness digital technology to improve logistics and supply chain** efficiency based on low carbon footprint farming.
3. **Build environmentally sustainable crop protection systems** to reduce pesticide use and improve market access.
4. **Build a skilled labour force** to utilize technology capability and support the horticulture industry of the future.
5. **Develop new products**, diversify product ranges for future consumer needs, for increased domestic and international market access.

Three systems level thinking were also identified to support the five transformational opportunities.

1. To capture and spread innovations more rapidly, creating probing systems to explore innovations in other sectors may help to 'leapfrog' the technology adoption curve in horticulture.
2. Design unique collaborative structures to encourage transformational R&D structure, such as the Defense Advanced Research Projects Agency (DARPA) model. Due to the limited funds in agriculture, a DARPA-light' approach may be utilised that draws across industry funds and brings together multi-disciplinary and sectoral teams to create a DARPA-like research teams for horticulture.
3. In addition to the specific crop Strategic Investment Plans, setting cross-industry goal could provide a platform to share knowledge and pool resources to tackle challenges that impact multiple crops.

The transformational thinking that addresses future challenges could be supported by consumer education on healthy and nutritious foods, addressing knowledge asymmetries, capacity building, and sharing information and discovery across all horticulture industry.

Keywords

Climate, Digital technology, Indoor-farming, Labour, Market access, Pesticides, Systems thinking

Introduction

The Australian \$15 billion horticulture industry comprises fruit, vegetables, nuts, flowers, turf, and nursery products. The fruit and nut industry, valued at \$5.4 billion in 2019/2020, includes crops such as avocados (\$328 million), bananas (\$647 million), mangoes (\$172 million), and macadamia (\$266 million). The Australian tropical and subtropical horticulture also includes niche and emerging crops with the potential for increased demand in local and international markets, such as lychees, custard apple, durian, cacao, coffee, sapote and vanilla. The horticulture industry is in northern Australia's tropical and subtropical areas, contributing significantly to the prosperity of people living in rural and regional Australia. The Australian horticulture industry enjoys proximity to ports and places to capitalise on international demand from its

domestic and international reputation as a sustainable producer of premium safe food.

Hort Innovation and industries have invested in R&D projects and programs to solve market failures and provide immediate solutions to industry pain points, which deliver incremental change at a crop-specific level. To support the vibrancy of the horticulture industry to solve the increasing pressures from climate change to growing populations, there is an imminent need to drive innovations, which would improve farm productivity, domestic consumption and international markets. In addition to the incremental change to deal with increasing social, political, economic, and environmental challenges, there is a need to identify opportunities for transformational change and build momentum that will result in longer-term industry resilience. Transformational thinking around research and solution development would support the horticulture industry to respond to the opportunities and challenges of production, supply chain, and long-term market access.

The key objective of this project was to apply a lean design process to identify challenges and opportunities for tropical and subtropical crops to guide research and development for the transformational benefit to the horticulture industry. In addition, the project provides a framework to guide strategic planning and investment in transformational R&D for sustainable, productive, profitable, and futuristic tropical and subtropical horticulture.

Methodology

Lean design was implemented to identify challenges and opportunities for tropical and subtropical crops for the transformational benefit of all horticulture industries. **An independent consultant (The Growth Drivers – TGD) was engaged to provide expert technical advice regarding the design, analysis and reporting of data obtained through the project activities.** The project conducted a series of stakeholder engagement activities, including a survey, interviews, and a workshop, to obtain industry and research perspectives.

Industry Survey

An online survey was developed and circulated to 98 key leaders across the horticulture industry. The survey questions were designed to identify key challenges facing the horticulture industry and at individual business levels in the next 5-10 years. In addition, the survey was intended to gain an initial understanding and prioritisation of the main future challenges facing the tropical and subtropical industry.

1-on-1 Interviews

Initially, focus groups were planned as a follow-up to the survey. However, upon reflection regarding the best way to uncover deep insights from key industry stakeholders, the project pivoted to interviews with researchers and industry representatives. These interviews inquired into crop-specific needs and built upon survey findings regarding future challenges and opportunities.

Quantitative Research (prompt document for workshop)

A prompt document was prepared capturing some processes for identifying drivers and opportunities for transformational R&D in tropical and sub-tropical agriculture in Australia. Quantitative research into innovation trends in horticulture and analogous industries was performed to provide a quantitative lens to the project findings and support the design and delivery of the industry workshop.

Industry Workshop

On the 8th of March 2023, a lean design workshop was held at the University of Queensland, Long Pocket Research Facility. Out of the 43 stakeholders invited, 22 people attended the workshop bringing together industry, government representatives, and researchers. The lead TGD consultant guided the participants through activities exploring significant future challenges and opportunities, including the qualitative insights developed from the survey and interviews and discussed the prompt document on quantitative research developed by Prof Damian Hine .

Results and discussion

Industry Survey and 1-on-1 Interviews

A total of 24 people from the industry responded to the survey. The respondents of the 1-on-1 interviews ranged from company directors to researchers and spanned several industries and regions. The interviews provided a high-level understanding of the main areas specific crops were researching and investing in. Interviewees also highlighted barriers to achieving research impact in the industry, from siloed projects to effective solutions struggling to receive funding for commercialisation.

The survey and interviews identified five main areas of the challenges that require transformational change across the different tropical and subtropical crops and regions. These include access to markets, changing environmental conditions and climate policy, biosecurity threats and pest incursions, increasing costs of production and a labour force that meet business needs.

The participants also provided insights into research and solutions development to support transformational change and address the challenges, including providing climate information to support decision innovative production practices and accelerate investments in production systems. In addition, transformational change is needed to address knowledge asymmetries, understand consumer preferences to enhance uptake of horticultural crops and develop R&D solutions that respond holistically to complex user systems through collaboration between businesses and industries.

Quantitative Research (prompt document)

The quantitative research identified that innovation in horticulture is currently years behind developments in other industries, such as defence and medicine. However, an opportunity to accelerate transformation in the horticulture industry is by adapting and building upon technical gains in other industries. The Defense Advanced Research Projects Agency (DARPA) ‘DARPA-light’ approach could be utilised that draws across industry funds and brings together multi-disciplinary and sectoral teams to create DARPA-like research teams for horticulture.

Industry Workshop

The key challenges and opportunities that would transform tropical and subtropical horticulture were highlighted. If addressed, they would have significant implications for the sustainability and prosperity of the industry. Future transformational R&D would provide solutions through:

1. New and improved knowledge of climate resilient production systems.
2. Harnessing digital tools to improve logistics and supply chains and reduce carbon footprint.
3. Tackling biosecurity risks and endemic pests challenges due to increasing pest resistance and MRL residues with agrichemical use that impact market access and productivity.
4. Supporting labour force to build capacity and skills for implementation of on-farm technologies; and
5. New product development and diversify product ranges targeting future consumer requirements and health benefits, and market access.

Outputs

Table 1. Output summary

Output	Description	Detail
Interview Protocol	This document includes engagement timeline & methodology, logic, and interview approach and line of enquiry.	This document summarises the approach the TGD team will take to conducting interviews with internal UQ researchers, and priority external industry stakeholders.
Prompt Document	This document captures processes for identifying drivers and opportunities for transformational R&D in tropical and sub-tropical agriculture in Australia	Taking into account research and development initiatives which are already flourishing in horticulture and other industries, the document considers how building on these technical gains could support Hort Innovation’s tropical and sub-tropical transformational R&D. Consideration is given to the commercial impact of how such innovations could improve on-farm practice and outcomes. It is hoped that such a document will be useful for longer term, strategic thinking which may spur ideas for co-investment in future technologies with a third horizon, future focus.
Stakeholder engagement activities	Report of survey, interview and industry workshop.	Stakeholder engagement activities, including a survey, 11 interviews, and a workshop, to identify crop specific and industry-wide challenges and opportunities as the desired outputs from this project. The final report highlights key transformation areas and insights provided through the lean design process undertaken by TGD.

Outcomes

Table 2. Outcome summary

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
Framework of strategic planning and investment in transformational R&D for sustainable, productive, profitable, and futuristic tropical and subtropical crops.	- Tools & advanced technologies. - Systems design: practice & management - Innovation & disruption	A four-step process used to identify high-priority recommendations from three stakeholders' engagement activities with key industry leaders and quantitative research on transformational thinking.	Survey, interview, prompt document and workshop reports (appendix 1, 2 and 3)
Strategic challenges that are likely to be faced by tropical/subtropical horticulture determined.	Outcome: Increased farm profitability, productivity and sustainability for horticulture growers as a forward-thinking approach for next 10 years with focus on transformational approaches and large multidisciplinary cross -sectoral initiatives.	Discussion on transition of thinking model from Horizon 1 to Horizon 3, considering the key drivers of climate, changing demographics, policy, economic land scape and new markets. This led to identification of key impact areas and systems level thinking changes to support transformational opportunities. - Implement climate-resilient production systems (controlled environments and outdoors) to enable growers to meet the demands of climate change. - Harness digital technology to improve logistics and supply chain efficiency based on low carbon footprint farming. - Build environmentally sustainable crop protection systems to reduce pesticide use and improve market access. - Build a skilled labour force to utilize technology capability and support the horticulture industry of the future. - Develop new products, diversify product ranges for future consumer needs, for increased domestic and international market access. Recommendations based on the lean design process captured.	Survey, interview and prompt workshop reports (appendix 1, 2 and 3).

Monitoring and evaluation

Table 3. Key Evaluation Questions

Key Evaluation Question	Project performance	Continuous improvement opportunities
To what extent has the project achieved its expected outcomes?	The project achieved all the expected outcomes as in Table 2.	Survey questions and interview protocols were reviewed by key project members.
How well has the intended audience been engaged in the project?	65 key stakeholders in horticulture industry were engaged	Stakeholders were followed up to confirm their participation and responses were obtained.
To what extent were engagement processes successful to the target audience/s of the project?	24 stakeholders were surveyed and 22 participated in the face-to-face workshop.	44% of the stakeholders identified attended the workshop and 32% of those invited responded to survey.
What efforts did the project make to improve efficiency?	Instead of focus group discussions, a 1-on-1 interview process was utilised to obtain in-depth information from stakeholders.	Online survey process was used to capture information from stakeholders and quantitative research into innovation trends in horticulture and analogous industries was performed.

Recommendations

1. There is a need for dynamic climatic model that are accessible to and usable by all growers to support them in making a myriad of decisions as they seek to **adapt to climate change** – from what to plant, how to grow it, and when to harvest, to long term rainfall, solar radiation, groundwater, the movement of pests and diseases, soil moisture etc to guide multi-generational planning.
2. Aligned with this, long term forecasts of demographics, international markets, competitive landscapes, consumer preferences and market share and market capture of international competitors would also encourage people to develop new products/varieties with point of differentiation and transition to more nutritional and sustainably grown produce over time– if this is deemed economically viable. Economic assessments of experimental and emerging crops would also assist the planning by growers. This will also require **significant consumer education efforts** to support the creation of demand instead of primarily responding to demand.
3. Automation and robotics are critical to **addressing labour shortages** in the short term, and implementing **precision agricultural solutions** that enhance productivity, respond to climate change and minimise emissions. However, the system these solutions exist within should be considered, including skill and capacity development, as well as regional development, so that workers and communities can transition to this new solution.
4. **Enabling digital and technological solutions** should operate within a holistic, flexible approach to respond to production systems.
5. **Controlled environment agriculture (CEA) or protected cropping** needs resource inputs for multiple outcomes in addition to climate independent increased productivity. These include renewed focus on high value crops, native crops, using CEA for understanding physiology for indoor and outdoor farming, shortening breeding timelines and life cycle analysis. Energy inputs will be a critical factor requiring innovative solutions.
6. Addressing both input and output needs, such as **reducing pesticide input** without reducing product quality to meet processor and consumer requirements, has the potential to reduce sustainability challenges.
7. **Accessing new markets** and R&D to overcome challenges limiting Australia's ability to compete in international markets, including the use of pesticides, a particular challenge that markets are increasingly intolerant.
8. **Integrating existing research and solutions** across tropical and subtropical and analogous industries is needed exploiting innovative tools and enablers.

Designing transformational solutions

Systems level thinking and changes to support transformational opportunities:

1. Explore innovations in other sectors that can help to 'leapfrog' the technology adoption curve in horticulture
2. Design unique collaborative structures to encourage transformational R&D, such as the DARPA model.
3. Setting cross-industry goals to tackle challenges that impact multiple crops and benefit from common platforms

Process

Given the reality that many of the technological developments, including those which are taking hold in adjacent industries offer strong signals to horticultural industries as to drivers and solutions to change across economic, environmental, and biosecurity - an analytical capability within Hort would support funding decisions across identified transformational areas to transition them from Horizon 1 to Horizon 2 and 3. Please note that funding for Horizon Two projects and programs of applied work carry a lower risk than funding for Horizon 3, therefore any funding portfolio should balance these risks.

Areas of focus -Strategic investment - Horizon 2 and 3 projects.

1. Develop implementation plans in the identified areas captured in the summary.
2. Build the analytical capabilities required to gauge emerging issues and opportunities among drivers such as demographics, weather and climate, technology developments.
3. Develop an experimental 'no-regrets' fund to test new to industry innovations that have the potential for high impact (horizon 3).
4. Long term resource provision for transformational research projects (7 to 10 years) linked with impact delivery capability retention, skills, and training, and building new capacity,

There are also major infrastructural requirements to deliver results that have the potential for impact. A key recommendation based on the assessments undertaken and the logic above points to the need of renewed and increased impetus on strategic cross-sectoral investments at Horizons 2 and 3 to deliver global leadership in future focused sustainable and profitable tropical and subtropical horticulture.

Refereed scientific publications

n/a

References

None

Intellectual property

No project IP or commercialisation to report.

Acknowledgements

The contributions of The Growth Drivers team in all the stakeholders' engagement activities and the report from the activities are greatly appreciated.

Appendices

1. Interview Protocol.
2. Appendix 2 Prompt Document
3. Final Report of stakeholder's engagement activities - Lean design workshop pilot: Identifying Transformational R&D Opportunities for the Tropical and Subtropical Horticulture Industry.

Survey Draft

Survey Introduction

Your input to this survey will help develop projects to find solutions with potential to dramatically change or overcome complex problems or opportunities horticulture faces in the medium to long term future (i.e. 5-10 years). It will be used to guide strategy and investment to drive a vibrant tropical/subtropical sector supplying domestic and international markets.

We really appreciate you taking the time to complete this 10 minute survey, and contributing your perspective on our future R&D strategy.

Enter privacy statement here:

Section 1: Demographic Questions

1. Name:
2. Company/ Business Name:
3. Role:
4. Which industries are you involved with:
a. (short answer text box)
5. Region: *(Tick box options)*
 - a. Carnarvon
 - b. Kimberley
 - c. Northern Territory
 - d. North Queensland
 - e. Central Queensland
 - f. Southeast Queensland
 - g. Northeastern NSW
 - h. Other (short answer text box)

Section 2: INDUSTRY Challenge Questions

QUESTION 1a. When thinking about your industry...

1. Please identify the most important challenge facing your industry over the next 5-10 years.
a. (short answer text box)
2. What is the likely impact on your industry if this challenge isn't solved?
a. (short answer text box)
3. What is the most effective way to solve this challenge (e.g. resources, technology, education etc)?
a. (Short answer text box)

QUESTION 1b. When thinking about your industry...

4. Please identify the next most important opportunity facing your industry over the next 5-10 years.
a. (short answer text box)
5. What is the likely impact on your industry if this opportunity isn't realised?
a. (short answer text box)
6. What is the most effective way to realise this opportunity (e.g. resources, technology, education etc)?
a. (Short answer text box)

Survey Draft

Section 3: BUSINESS Challenge Questions

QUESTION 2a. When thinking about your business...

1. Please identify the most important challenge facing your business over the next 5-10 years.
a. (short answer text box)
2. What is the likely impact on your business if this challenge isn't solved?
a. (short answer text box)
3. What is the most effective way to solve this challenge (e.g. resources, technology, education etc)?
a. (Short answer text box)

QUESTION 2b. When thinking about your business...

4. Please identify the next most important opportunity facing your business over the next 5-10 years.
a. (short answer text box)
5. What is the likely impact on your business if this opportunity isn't realised?
a. (short answer text box)
6. What is the most effective way to realise this opportunity (e.g. resources, technology, education etc)?
a. (Short answer text box)

Professor Damian Hine
Dr Natalie Lewandowski
Dr Edgar Brea

A prompt document: Some processes for identifying drivers and opportunities for transformational R&D in tropical and sub-tropical agriculture in Australia



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This is a prompt document to elicit ideas from participants in the workshop, during and particularly following the workshop. The ideas included in this document are only a sample of what could be used to develop a transformational R&D strategy for tropical and subtropical horticulture. The knowledge and experience of our workshop participants will certainly produce more and better insights that we will seek to capture.

Introduction

What is contained in this document is not a comprehensive assessment of transformational R&D across industries. This is a prompt document designed to be thought provoking rather than offering a strategic pathway forward. The document builds on information from the identified challenges and opportunities for tropical/subtropical horticulture in the Insights report prepared by TGD. Taking into account research and development initiatives which are already flourishing in horticulture and other industries, the document considers how building on these technical gains could support Hort Innovation's tropical and sub-tropical transformational R&D. Consideration is given to the commercial impact of how such innovations could improve on-farm practice and outcomes. It is hoped that such a document will be useful for longer term, strategic thinking which may spur ideas for co-investment in future technologies with a third horizon, future focus.

It is hoped that this document can assist the workshop you are attending by providing food for thought on how innovation from other industries, as well as new approaches to existing problems in the tropical/subtropical industries.

Methodology

Building on the outcomes from the TGD Interview Insights Snapshot report, we have taken a Three Horizon approach and investigated various industries that have developed innovative solutions to problems which could be applied in horticulture production in tropical and subtropical regions of Australia. What is presented is a means to capture the pathways along which technologies emerge and diffuse from their origins to other industry sectors.

The 3 Horizon approach consists of:

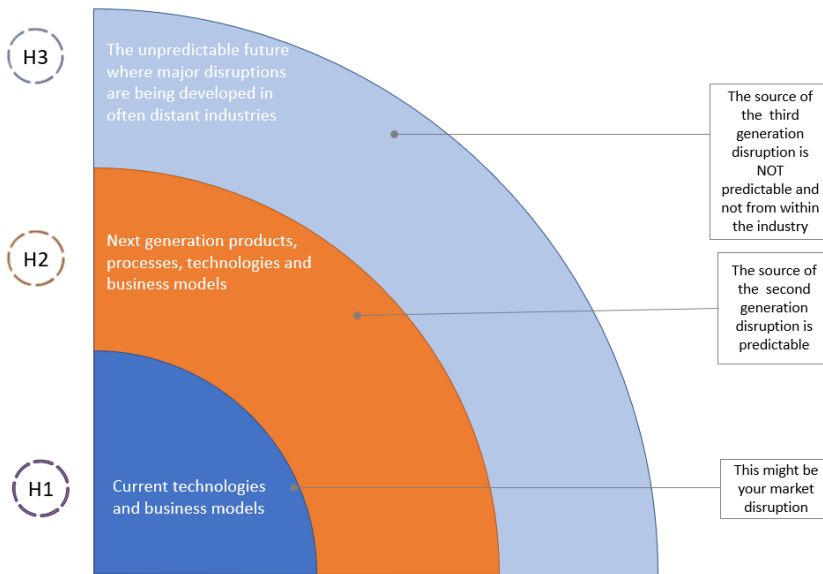


Figure 1: The 3 Horizon Approach

These potential opportunities are longitudinally divided into three main phases, namely horizon 1 (H1), horizon 2 (H2) and horizon 3 (H3) opportunities. The division aligns with the three horizons methodology, originally proposed by Baghai, Coley and White's book *The Alchemy of Growth*, as a framework to design growth strategies by assessing future opportunities while acknowledging the foundation the current situation offers. According to the framework, H1 represents current core business sustaining a business or an industry, and opportunities here focus on improving performance, particularly through innovations that seize new opportunities for growth. H2 opportunities comprise those emerging opportunities that are more likely to generate considerable profitability in the near to medium term. H3 opportunities represent disruptive non-linear ideas that may emerge to either limit existing opportunities or create substantial new ones. It is about imagining completely new ways of doing things, technologies (and businesses) that may enter the market from other industry sectors, and large step change that would shake up the industry that the industry needs to prepare and strategize for.

What's driving change across the three horizons?

We understand that the key change drivers for tropical and sub-tropical horticulture, and for Hort Innovation are:

- Climate
- Demographic
- Economic
- Policy/regulation
- Non-food markets

These five drivers are not unique to the area of subtropical horticulture and hence the traditional approach of looking at existing data within the one industry and searching for ideas only within the parameters of horticulture while still important, will be mixed with a view of cutting edge initiatives and activities from other industries that can offer innovative solutions to the shared identified problems within tropical and subtropical horticulture.

Building on this, we know that technological developments and changes in practice do not always emerge within the industry that they are applied in. Assessing the emergence and evolution of technologies which have had substantial impact in recent times requires us to scan many industries beyond horticulture or even agriculture. An example of this would be the impacts of

digitisation and digital transformation as well robotics, which emerged from industries where there was an imperative to automate, for health, safety, access, cost, skills shortage, energy and environmental reasons. Automation also speeds processes which supports a competitive agenda in industries such as defence, aeronautics, space, automotive, manufacturing and mining.

Looking closer to home – Agribusiness as a whole system

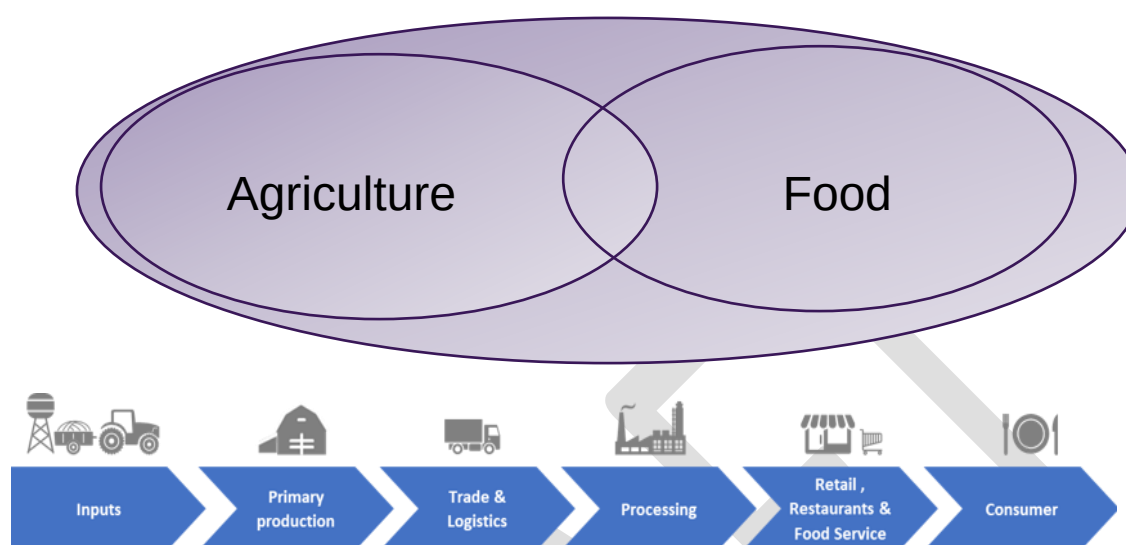


Figure 2: Agrifood system and supply chain.

Within agriculture, agribusinesses have resources to adopt new practices and technologies and integrate those in to their business model sooner than most. This means that agribusiness is the key to impacting the farm - not the farm themselves. Post farm gate drives the farmers – agrifood, food and retail get closer to the consumer and can respond to changing demographics and consumer preferences. A two-way flow of data along the supply chain would provide greater insight and adaptability to consumer preferences. This varies by country and region, so comparative data would need to be assessed on preferences in comparable national markets.

Transformational R&D actions and processes

Transformational R&D is categorised by R&D that when adopted will completely reshape the organisation or sector it is applied in, this is not a short game and often takes 10+ years to develop and implement.

Horticulture is a net adopter of innovations. As such, proportionally few innovations that have emerged in horticulture have their origins in the industry. Major developments in genetics, genomics, microbiology largely come from human health and biopharmaceuticals. Much AgTech is derived from automotive, aeronautics, manufacturing, and warehousing. As an example, Artificial intelligence is a platform technology which has been available in various forms for the last 30 years, but has recently leapt ahead through the developments in deep learning and across industry boundaries to have a more extensive role in precision and predictive agriculture. Looking more broadly we can consider the following examples of changes which have taken transformational R&D forward in various industries:

Example 1: How does one jump from a car into a space rocket? (Tesla)

SpaceX, founded by Elon Musk, has leveraged several technological innovations from Tesla to develop their SpaceX rockets. One of the key innovations they have developed is advanced battery technology, which is used in Tesla's electric vehicles and is ideal for powering the systems in SpaceX's rockets. These rockets also use high-performance electric motors, another technology which was developed by Tesla. Such motors allow for precise control of the rocket's thrust and acceleration, contributing to the efficiency and cost-effectiveness of SpaceX's operations.

SpaceX has also benefited from Tesla's expertise in software development. The rockets use sophisticated software systems to control their descent and landing, similar to the Autopilot system used in Tesla's cars. Additionally, SpaceX has adopted Tesla's vertically integrated supply chain approach, which allows them to control the manufacturing and assembly of key components in-house.

These innovations have allowed SpaceX to make significant advancements in space travel and exploration, including reusable rockets and plans for interplanetary travel. By leveraging these technologies from Tesla, SpaceX has demonstrated the power of cross-industry collaboration and the potential for technological advancements to revolutionise multiple fields.

Example 2: What can a vaccine inject into agriculture? (RNA)

RNA interference (RNAi) technology has been used in horticulture to introduce specific genetic modifications in plants for the purpose of enhancing desirable traits such as resistance to pests and diseases, improved nutritional value and increased yield.

One of the earliest applications of RNAi in horticulture was to develop plants that are resistant to plant viruses. This technology was first demonstrated in 2002, when scientists used RNAi to protect tobacco plants from the tobacco mosaic virus. Since then, RNAi has been used to develop virus-resistant crops, including tomatoes, potatoes, and cucumbers.

RNAi has also been used to develop crops with improved nutritional value, for example, scientists have used RNAi to increase the production of vitamins and other nutrients in crops such as rice, corn, and soybeans. This technology has the potential to address nutrient deficiencies in populations that rely heavily on these crops as dietary staples.

A more recent applications of RNAi in horticulture is to suppress genes involved in plant ripening and senescence, leading to fruits and vegetables with longer shelf-lives.

Overall, RNAi technology has demonstrated great potential for improving crop traits and increasing crop yields in horticulture. While some of these applications have been in use for over a decade, others are more recent and still under development.

The markets for this technology are extensive. Numerous tropical and subtropical horticulture crops have faced significant pest and disease challenges in the last ten years including:

1. Banana: Fusarium wilt (Panama disease), caused by the fungus *Fusarium oxysporum* f. sp. *Cubense* has wiped out entire plantations of bananas in several countries, including Australia, China, the Philippines, and parts of Africa and Latin America.
2. Citrus: Citrus greening or Huanglongbing (HLB) is a bacterial disease that affects citrus trees causing economic losses in citrus-producing regions worldwide, including the United States, Brazil, and China.
3. Cocoa: Cocoa production has been threatened by several diseases, including Black pod disease, caused by the fungus *Phytophthora* spp., and Frosty pod rot, caused by the

fungus *Moniliophthora roreri*. These diseases have caused significant yield losses in several cocoa-producing countries, including Ghana, Ivory Coast, and Ecuador.

4. Coffee: Coffee rust or *Hemileia vastatrix*, a fungal disease that affects coffee plants has caused losses in coffee production in several countries, including Colombia, Costa Rica, and Guatemala.
5. Mango: The most significant pest affecting mango production is the fruit fly, which causes significant yield losses and can limit export opportunities in several mango-producing countries, including Australia, India, Thailand, and the Philippines.

The application of RNA solutions across multiple crops and industries makes it a platform technology with wide-ranging application.

Example 3: How did nanotechnology and biotechnology build establish the pathway to BioClay?

Bio-clay is a novel nanomaterial that has been developed using innovations in bio-molecular and nano-technology. The material is composed of positively charged clay particles coated with double-stranded RNA molecules that target specific plant genes. When applied to crops, the bio-clay is taken up by the plants and delivers the RNA molecules to their cells, where they can selectively silence target genes and enhance desired traits.

The development of BioClay is based on several key innovations in bio-molecular and nano-technology, including the ability to produce and stabilise RNA molecules, as well as the use of clay particles as delivery vehicles for these molecules. The resulting material has several advantages over traditional genetic modification techniques, including greater specificity, reduced off-target effects, and faster regulatory approval. Bio-clay has several potential applications in agriculture, including the development of crops with increased resistance to pests and diseases, enhanced nutritional value, and improved yield. The technology also has the potential to be used for environmental remediation and as a tool for studying gene function in plants.

Key dates in the RNAi timeline

- 1998 - Fire and Mello discover RNAi mechanism in *C. elegans*
- 2001 - Elbashir proves first in-cell RNAi mediated gene silencing
- 2003 - Song proves first in-mouse RNAi-mediated gene silencing
- 2004 - First clinical trial on local delivery of siRNA²⁷ by Allergan and Sime Therapeutics
- 2005 - Song proves first in-mouse carrier-mediated RNAi-mediated gene silencing
- 2006 - Fire and Mello win Nobel Prize in medicine for discovery of RNAi
- 2006 - Alnylam proves first in human RNAi therapeutics
- 2008 - Calando Pharmaceuticals initiates the first clinical trial of targeted delivery of siRNA: CALAA-01
- 2010 - Alnylam proves first in human RNAi therapeutics
- 2013 - First demonstration of highly potent siRNA-mediated gene knockdown by Coelho
- 2018 - FDA approves the first siRNA therapeutics ONPATRO

Developments in human health receive much more funding than agriculture. It is then no surprise that many breakthroughs occur there. But are soon embraced by agricultural researchers.

Key dates in the BioClay timeline

- 2011 - BioClay concept conceived
- 2012 - Gate Foundation Grand Challenges Exploration Award
- 2014 - Queensland Government Accelerate Partnerships Grant.
- 2015-16 - BioClay protects plants from viruses in glasshouse trials- It works!
- 2017 - BioClay article in *Nature Plants*
- 2019 - ARC Research Hub for Sustainable Crop Protection

Figure 3: Developments in biomedicine embraced in agriculture – the BioClay example.

Example 4: Since when does compost power planes? (Biofuel)

The development of biofuels has been a gradual process that has been driven by several key innovations over time. Wood could be considered the earliest form of biofuel, however the modern biofuel industry began to emerge in the 20th century with the development of new technologies and production methods. One of the key innovations in the development of biofuels was the invention of the diesel engine by Rudolf Diesel in 1892. This eventually led to the development of biodiesel, which is produced from vegetable oils and animal fats and can be used as a substitute for diesel fuel. The discovery of how to produce ethanol from corn was first achieved in the United States in the 1970s. This led to the development of the corn ethanol industry, which has become a major source of biofuels in the US. More recent innovations include the development of second-generation biofuels, which are produced from non-food crops, agricultural waste, and other organic materials. These fuels are more sustainable and have the potential to be produced on a larger scale than first-generation biofuels. These innovations have enabled the growth of the biofuels industry and have helped to make renewable energy a more viable alternative to traditional fossil fuels.

These examples demonstrate often non-linear jumps of technology into another industry which allows the industry to benefit and build on existing innovation.

Predictiveness and predictability

A lag exists between when the technological solutions are introduced in their original sector and the uptake and adoption by other sectors. This can be based on need, but typically contains elements of the economic function of willingness and ability to pay. For horticulture, as a net adopter of developments from other industry sectors, the predictiveness of what developments will emerge, when and how they can be adopted and implemented is much higher than in cutting edge fields such as robotics, aeronautics, space, mining, automotive, biomedicine and human health. While disruptive technologies still impact the industry, choosing where to focus the transformational R&D dollar is enabled by an evidence-based assessment of disruptions emerging in other sectors.

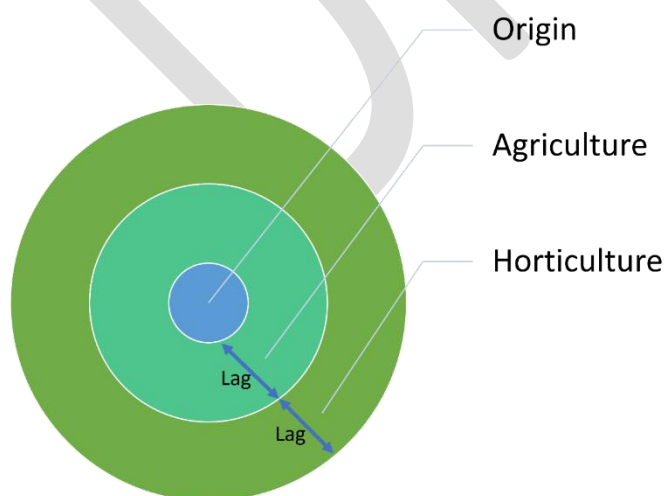


Figure 4: Innovation adoption into agriculture and horticulture industries.

Horticulture often witnesses the emergence, adoption and uptake of new developments after other areas of agriculture. This makes it quite possible to follow disruptions that emerge and then diffuse across sectors before they arrive in horticulture. This also provides a distinct opportunity for funders as well as businesses and peak bodies to play catch up with other sectors where a systematic analytical framework can be established. Seeing the disruptions emerge as early as possible provides the chance to focus attention and resourcing at these areas of investment.

Keeping in mind the 3 Investment themes for Hort Innovation, we have linked these with the insights from the TGD document and then expanded on these into simple short examples of innovations from other industries which may provide a third horizon solution. We note that there are possible interrelations from all insights however the purpose of this exercise is to simply demonstrate the interconnectivity and possible applications from other industry areas:

Hort investment theme 1, Understanding crops for future 'smart farms' linking to TGD Insight 1, Preparing for climate change

One example of a non-linear innovation industry that could help sub-tropical agriculture prepare for the impacts of climate change is precision agriculture. Precision agriculture involves the use of technology such as sensors, GPS, and drones to gather data on crops and soil conditions, which can then be used to optimise crop yields while minimising environmental impacts. For example, in sub-tropical regions where water resources are limited, precision irrigation systems could be used to target water delivery to specific areas of a field based on real-time data on soil moisture levels. This could help to reduce water usage and minimise the impact of drought conditions.

Another example of a non-linear innovation industry that could help sub-tropical agriculture prepare for climate change is biotechnology. Advances in biotechnology have led to the development of crops that are more resilient to environmental stresses such as drought, heat, and pests. For example, researchers are developing crops that can tolerate high temperatures, which could be particularly important in sub-tropical regions where temperatures are expected to increase as a result of climate change. Biotechnology could also be used to develop crops that are resistant to pests and diseases, reducing the need for chemical pesticides and increasing crop yields.

Hort investment theme 1, Understanding crops for future 'smart farms' linking to TGD Insight 7, Addressing knowledge asymmetries

Knowledge asymmetry refers to the situation where some parties in a transaction have more or better information than others. In the context of horticultural industries, knowledge asymmetries can occur between farmers, distributors, and consumers, leading to inefficiencies in the supply chain and reducing the quality and value of the final product.

One way to address knowledge asymmetries in horticultural industries is to leverage innovations from other industries that have addressed similar challenges. Innovations from the finance industry, such as risk management tools and financial instruments, could be adopted. For example, weather-based insurance products could help farmers to manage risks associated with changing climatic conditions, while financial instruments such as futures contracts could help to stabilise prices and reduce information asymmetries between farmers and distributors.

Hort investment theme 2, Improving crop systems and management linking to TGD Insight 3, Efficient production systems

Robotics innovations from other industries, such as manufacturing and healthcare, could be adapted to innovate horticultural industries in several ways. For example, autonomous robots equipped with sensors and cameras could be used to monitor crop growth, detect diseases and pests, and apply targeted treatments, reducing the need for manual labour and increasing efficiency. Robots could also be used for precision seeding, planting, and harvesting, improving the accuracy and quality of the final product. Additionally, robotic systems could be used to optimise water and nutrient delivery to plants, reducing waste and improving sustainability. By leveraging robotics innovations from other industries, horticultural industries can increase productivity, reduce costs, and improve the quality of their products.

Hort investment theme 2, Improving crop systems and management linking to TGD Insight 5, Managing R&D investments across 'inputs' and 'outputs'

Several innovations from other industries could be adapted into horticulture to improve return on investment (ROI) for farmers. One such innovation is precision agriculture, which uses technology such as drones, sensors, and data analytics to optimise crop management practices such as fertilisation and irrigation, reducing waste and improving yields. Robotics and automation could also be used to reduce labor costs and increase efficiency, while genetic engineering and biotechnology could lead to the development of crops with higher yields and improved resistance to pests and disease. By adapting these and other innovations from other industries, horticultural farmers can improve their ROI and ensure long-term sustainability of their operations.

Hort investment theme 3, Enabling tools and technologies linking to TGD Insight 2, Understanding consumer preferences, TGD Insight 4, Holistic R&D and TGD insight 6, Accessing new markets

Innovations from other industries can help horticultural industries better understand consumer preferences and access new markets in several ways. For example, data analytics and artificial intelligence (AI) technologies used in industries such as retail and e-commerce can be applied to analyse consumer behavior and preferences in horticultural products. This can help horticultural businesses tailor their products to meet consumer demands and create targeted marketing campaigns. Innovations from the finance industry, such as mobile payments, can help horticultural businesses access new markets and improve supply chain efficiencies. Mobile payments can make it easier for businesses to reach consumers in remote or underserved areas, allowing them to access new markets and increase revenue.

These examples demonstrate how innovations from other industries could or already are transforming the way in which horticulture operates in the future.

Seeing patterns in numbers – Patent, product and market metrics

On the following page we have a heatmap of over 80,000 horticulture relevant patents from 2003-2022 by CPC (Cooperative Patent Classification) codes as generated by Lens (a scholarly patent aggregator). The heatmap demonstrates the top ranked areas for growth in patent numbers for each year. A dark red box indicates that that patent area was the highest for the year, while a grey box means that there were very low or no patents in that area of that year. This heatmap shows CPC areas which have been growing since 2015 (the information on the CPC code areas used in this heatmap are indexed in **Appendix 1**).

When considering the heatmap, there are some interesting patterns emerging:

- computing arrangements based on biological models;
- arrangements of electric circuit (sensors);
- lighting devices;
- medical instruments/methods are becoming quite popular – linked to protected cropping and intensive farming.

These four patterns are all system components of larger families of technologies including IoT smart farms (sensors, lightning devices), digital twins (computing arrangements), and tech from the medical sector to perhaps prevent plant diseases. Reading through the codes in **Appendix 1** will provide further insight into the tech areas involved in each heatmap code, and this demonstrates links to areas of an emerging technology. Such a systematic analysis of patents can be a signal of growing investment, scientific and commercial interest) that can be used to identify Horizon three trends in horticulture.

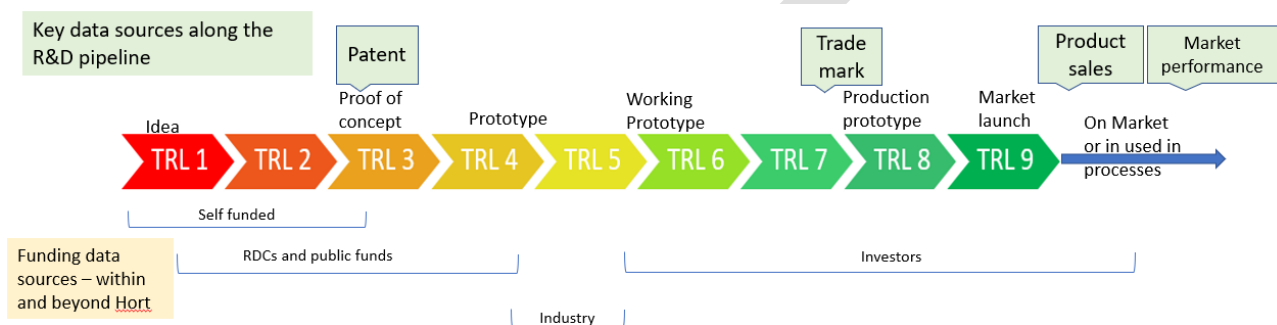


Figure 5: Data sources to assess transformational R&D opportunities in horticulture and other industries

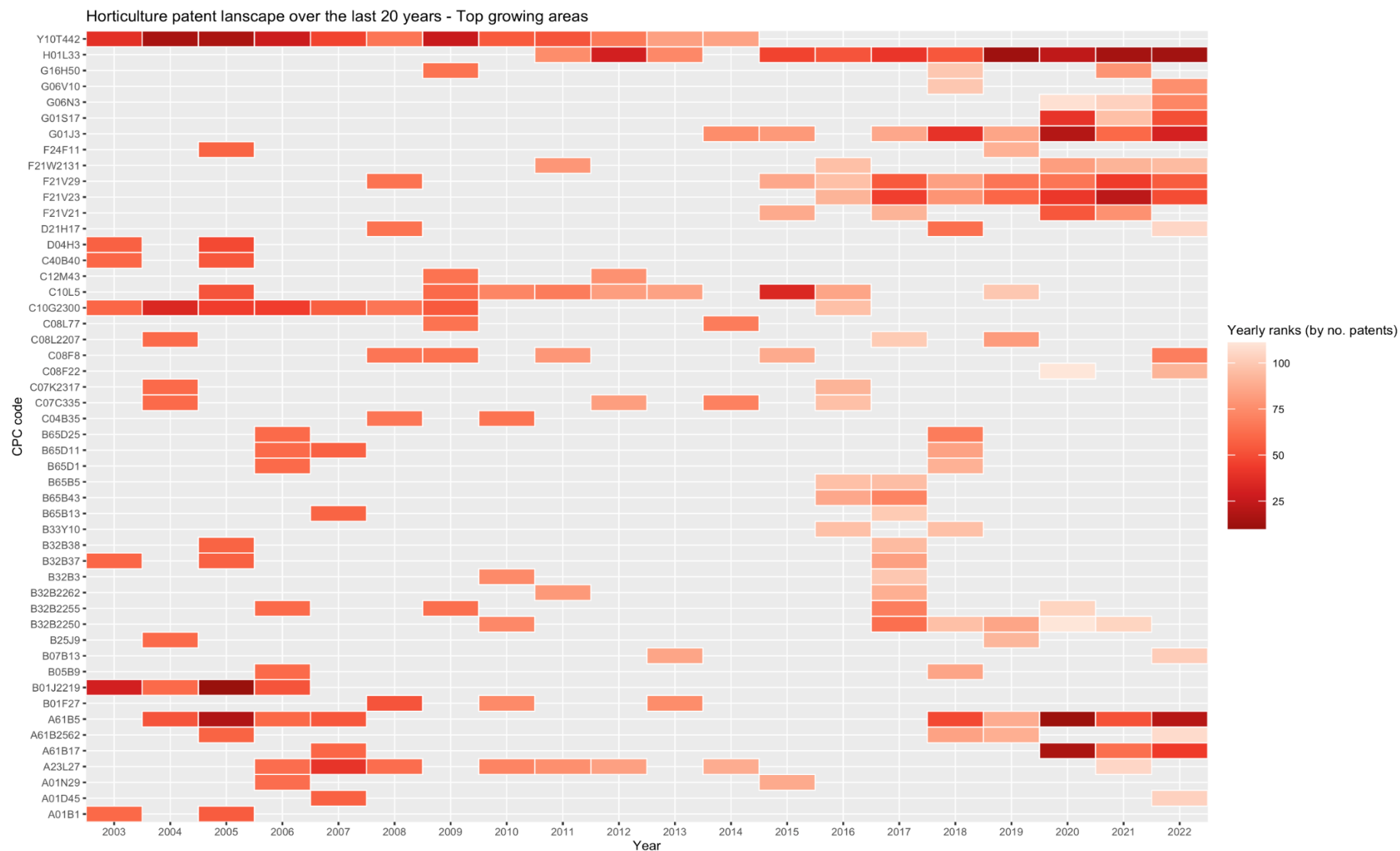


Figure 6: Patent heatmap, horticulture landscape over the last 20 years (generated March 2023)

Considering the above heatmap and the horizon model approach, it is useful to extrapolate our investigation into industries where technological innovation is occurring in order to consider how such trends would influence R&D for Hort Innovation. In Horizon two and three, disruptions or innovations can come from either unrelated industries (primarily cutting edge well-funded industries and their agencies, e.g.: defence) and adjacent industries (agriculture related). The following graph illustrates how we can look out to other areas to consider future R&D horizons for Hort innovation. The field of study in defence have varied substantial year by year as new drivers, scientific and technical breakthroughs, and most particularly new policy settings emerge to drive new agendas and efforts. In this case there may be a confluence between computer science and biology in defence R&D. But this would need further probing to see the extent of overlap between the two:

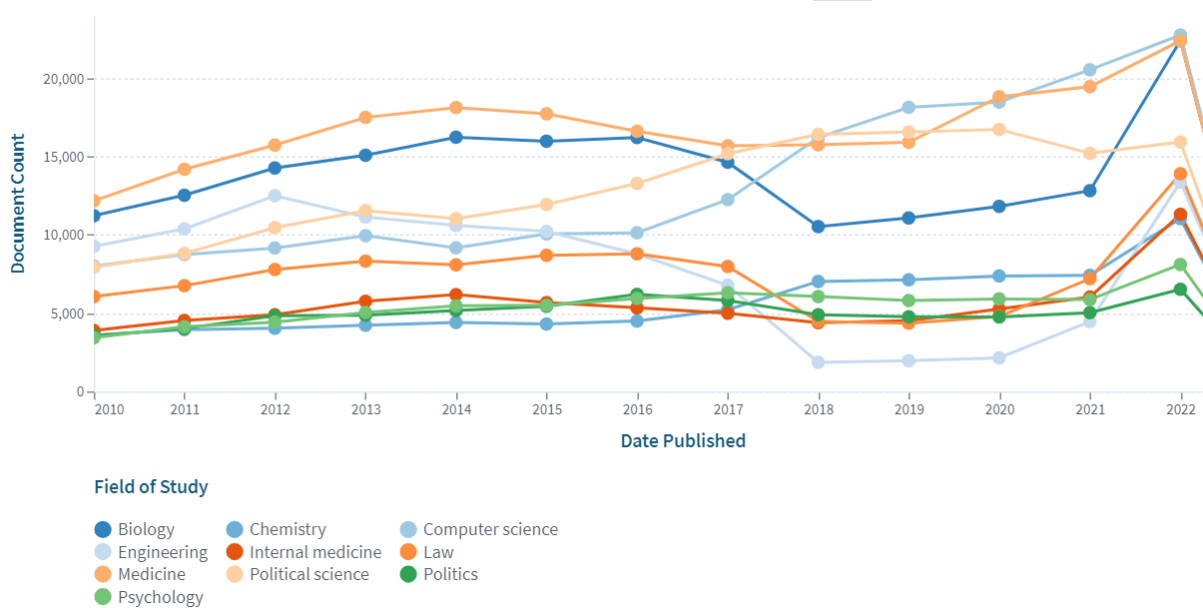


Figure 7: Number of scholarly works in relation to the defence Industry by field of study (generated February 2023)

Diagram 5 shows that we have seen recent increases in contributions to defence from other fields of study including Engineering, Computer Science, Medicine and Law. Extrapolating on this theme, considering the number of patents in a leading innovation industry, such as Aerospace, and considering the areas in which these patents are being made would also provide food for thought for Hort Innovation's approach to future R&D investment areas, as demonstrated by this diagram:

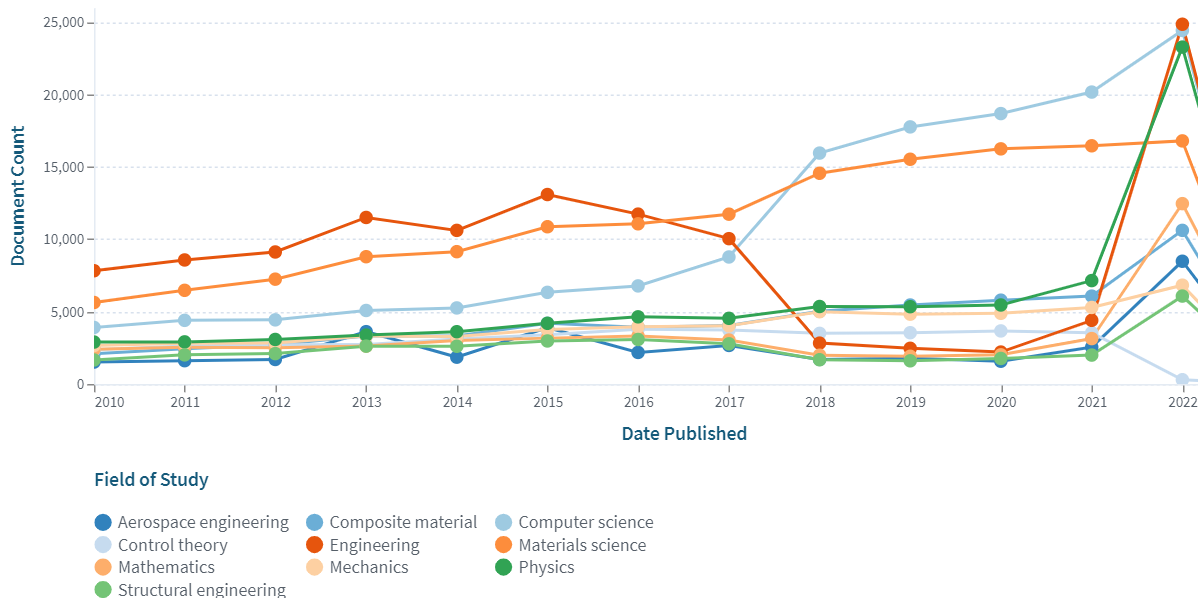


Figure 8: Number of patents in relation to the aerospace industry by field of study (generated February 2023)

Diagram 6 is another way to look at the number of patents which are emerging from other fields of study, most notably in this chart we can see high contributions from Engineering and Physics, but also a strong increase from Mechanics and the science of Composite Materials.

The influence of funding agencies – at the leading and bleeding edge

International funding agencies provide us with a further avenue to explore what the hot areas of investment are in R&D. Again, considering agencies which are not directly related to horticulture is useful when we are taking a Horizon approach – after all, the technology in our cars didn't necessarily originate at the industry – potentially coming from NASA or even F1. With this mindset, we are presenting information from the United States Defence Advanced Research Projects Agency (DARPA) and the United States Department of Agriculture (USDA). These agencies have very large investment budgets for R&D, but their strategy to invest is not necessarily considered as a traditional approach, especially in the project management model used by DARPA. DARPA's mission is to:

...make pivotal investments in breakthrough technologies for national security...The genesis of that mission and of DARPA itself dates to the launch of Sputnik in 1957, and a commitment by the United States that, from that time forward, it would be the initiator and not the victim of strategic technological surprises.

(Source: <https://www.darpa.mil/about-us/about-darpa>)

This mission indicates that DARPA's investment strategy is cutting edge, with their investment in R&D trickling down to other industries over time. Looking in more detail at the projects they have recently supported provides insight on areas of potential Horizon three investment for Hort Innovation:



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Exhibit R-2, RDT&E Budget Item Justification: PB 2023 Defense Advanced Research Projects Agency											Date: April 2022	
Appropriation/Budget Activity					R-1 Program Element (Number/Name)							
0400: Research, Development, Test & Evaluation, Defense-Wide / BA 1: Basic Research					PE 0601101E / DEFENSE RESEARCH SCIENCES							
COST (\$ in Millions)	Prior Years	FY 2021	FY 2022	FY 2023 Base	FY 2023 OCO	FY 2023 Total	FY 2024	FY 2025	FY 2026	FY 2027	Cost To Complete	Total Cost
Total Program Element	-	449.322	443.842	401.870	-	401.870	396.555	439.811	447.586	447.640	-	-
CCS-02: MATH AND COMPUTER SCIENCES	-	273.633	293.845	224.416	-	224.416	208.185	248.752	264.013	256.785	-	-
ES-01: ELECTRONIC SCIENCES	-	28.681	16.361	17.645	-	17.645	29.153	34.178	52.200	52.410	-	-
ES-02: BEYOND SCALING SCIENCES	-	57.365	65.145	70.188	-	70.188	58.923	58.940	43.250	53.540	-	-
MS-01: MATERIALS SCIENCES	-	53.663	40.303	58.356	-	58.356	82.602	89.818	80.000	76.782	-	-
TRS-01: TRANSFORMATIVE SCIENCES	-	35.980	28.188	31.265	-	31.265	17.692	8.123	8.123	8.123	-	-

Table 1: DARPA Investment by area

(Source: https://www.darpa.mil/attachments/U_RDTE_MJB_DARPA_PB_2023_APR_2022_FINAL.pdf)

Table 2 shows, at a very high level, that investment into mathematics and computer sciences, electronic sciences, beyond scaling sciences (which relates to the greater public good of a project, or the trickle into other areas), materials sciences (the study of the properties of solid materials and how those properties are determined by a material's composition and structure) and transformative sciences (which involve ideas, discoveries or tools that can radically change the understanding of an important existing concept in science, engineering or education). What is apparent is the emphasis on transformational applications of innovations which they are funding, understanding that the investment will not only have an impact in defence but also, other industries over time.

Furthermore, DARPA highlights that:

The Transformative Sciences project supports research and analysis that leverages converging technological forces and transformational trends in information-intensive subareas of the social sciences, life sciences, and manufacturing. The project integrates these diverse disciplines to eliminate reliance on foreign sources for critical materials, improve military adaptation to sudden changes in requirements, threats, and emerging/converging trends, especially trends that have the potential to disrupt military operations or threaten National Security. Specific research in this project will investigate technologies to enable detection of novel threat agents (e.g., bacterial pathogens) and maintain warfighter health and improve recovery. This project also includes efforts to create innovative materials of interest to the military, as well as biological platforms for fabrication.

(Source:

https://www.darpa.mil/attachments/U_RDTE_MJB_DARPA_PB_2023_APR_2022_FINAL.pdf)

DARPA's approach offers an "alternative model for funding cutting-edge R&D" ([Dubois](#), accessed March 2023) which aligns with the understanding that we live in a world which is complex and dynamic and certainly not linear. DARPA's R&D strategy is flexible enough to quickly exploit emerging situations and operates as an "investment firm" rather than and R&D lab – which highlights how they search for and exploit externally generated ideas and invest in those rather than attempt to generate ideas in house. Their flat organisational structure, organised thematically means their operation is flexible and hires and invests according to projects which they are aligning with. DARPA uses the following criteria when investing in R&D:

DARPA Investment Criteria

- What are you trying to accomplish?
- How is it done today and with what limitations?
- What is truly new in your approach which will remove current limitations and improve performance? By how much?
- If successful, what difference will it make?
- What are the mid-term, final exams or full-scale applications required to prove your hypothesis? When will they be done?
- What is the DARPA “exit strategy?”
- How much will it cost?

DARPA still supports *high-payoff*, core technologies

- Information Technology
- Materials, Mathematics, Biology
- Micro/nano systems
- “The Intersection of Biology, Information, Materials and Microsystems”

Figure 9: DARPA Investment Criteria ([Dubois](#), accessed March 2023)

The above criteria offer DARPA flexibility in their R&D, and reflect their project rather than program focus. Importantly, through outsourcing they minimise their risk and allow for a multidisciplinary and synergistic approach that reflects the non-linear nature of the world we live in and the problems it does and will present, this is supported by a study of DARPA in which the agency is compared to more traditional government funding bodies:

[A] significant factor shaping the programs is the agency’s mission in supporting radical, discontinuous technological change. That mission, as we have already mentioned, is rooted in DARPA’s origins in 1958 as a response to the Russian launching of Sputnik and the way in which Sputnik caught the U.S. military and scientific establishments by surprise.

(Source: [Poire, Colatat and Reynolds 2019](#))

Although the level of funding, and areas of funding in which DARPA operates could be considered vastly removed from Hort innovation, the key factor within the information presented lies in the manner in which DARPA approaches its R&D as an advanced research project agency. The criteria they apply to R&D selection, alongside their understanding of the benefits of transformational innovation could be applied to Hort Innovation.

The USDA, similar, to DARPA, investments in innovations which flows to other industries, a point which can be demonstrated by their interest in Artificial Intelligence:



B. Accomplishments/Planned Programs (\$ in Millions)

Title: Foundational Artificial Intelligence (AI) Science

Description: The Foundational Artificial Intelligence (AI) Science thrust is developing a fundamental scientific basis for understanding and quantifying performance expectations and limits of AI technologies. Current AI technologies are challenged in handling uncertainty and incompleteness of training protocols and data. This has prevented the successful integration of AI technology into many transformative DoD applications. To address these limitations, the Foundational AI Science thrust will focus on the development of new learning architectures that enhance AI systems' ability to handle uncertainty, reduce vulnerabilities, and improve robustness for DoD AI systems. One focus area of this thrust is the ability to detect and accommodate novelty - i.e., violations of implicit or explicit assumptions - in AI applications. Another focus area is the development of a model framework for quantifying performance expectations and limits of AI systems as trusted human partners and collaborators. A third focus area is the development of new tools and methodologies that enable AI approaches for accelerated scientific discovery. The technology advances achieved under the Foundational AI Science thrust will ultimately remove technical barriers to exploiting AI technologies for scientific discovery, human-AI collaboration, accommodating novelties, and other DoD relevant applications.

FY 2022 Plans:

- Continue development of novelty generators and novelty-robust AI techniques to create and identify rapidly and respond appropriately to new agents, actions, relations, and interactions.
- Demonstrate and evaluate novelty generators and novelty-robust AI techniques compared to non-robust methods performing on known tasks incorporating new agents, actions, relations, and interactions.
- Develop methods to accurately correlate data across multiple sources, such as lab notebooks, tables, figures, and experimental databases.

FY 2021	FY 2022	FY 2023
60.420	58.050	43.692

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Defense Advanced Research Projects Agency

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Table 2: USDA Investment in AI

(Source: <https://www.nifa.usda.gov/grants/funding-opportunities/artificial-intelligence-ai-research-institutes>)

The US Department of Agriculture is responsible for overseeing agriculture, forestry, and food-related programs. The USDA provides funding for a wide range of research projects aimed at improving food production, food safety, and the sustainability of agricultural practices.

Currently the USDA allocates funding into R&D based on its 4 priority areas;

- 1) Advancing Racial Justice, Equity, Opportunity, and Rural Prosperity
- 2) Addressing Climate Change via Climate-Smart Agriculture, Forestry, and Clean Energy
- 3) Tackling Food and Nutrition Insecurity
- 4) Creating More, Better, and New Market Opportunities

USDA FY 2022-2026 Strategic Plan

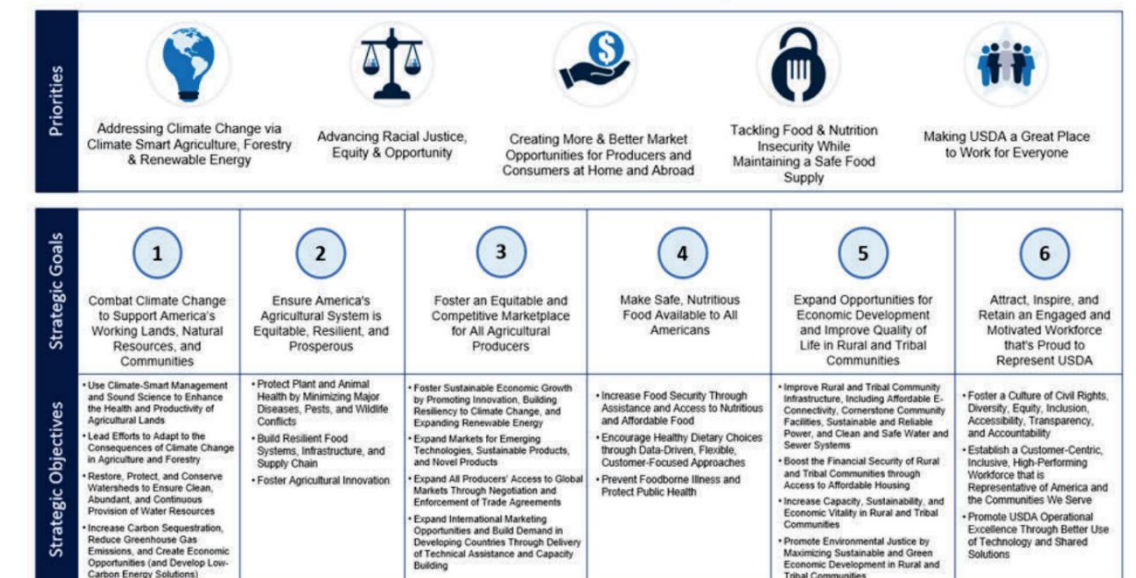


Figure 10: USDA FY 2022-2026 Strategic Goals and Objectives (Source: [USDA.gov](https://www.usda.gov))

One major area of research that the USDA funds is crop improvement. This includes developing new plant varieties that are resistant to pests, diseases, and environmental stressors, as well as improving crop yields and nutritional quality. The USDA also funds research related to livestock production, including breeding, genetics, and nutrition. Another area of research that the USDA focuses on is food safety. This includes developing new methods for detecting and preventing foodborne illnesses, as well as improving the safety of meat, poultry, and egg products.

In recent years, the USDA has also increased its funding for research related to climate change and its impact on agriculture. This includes developing new technologies and practices to reduce greenhouse gas emissions from agriculture, as well as improving the resilience of crops and livestock to extreme weather events.

The USDA is investing in gene editing technology which allows researchers to make precise changes to the DNA of plants and animals, which could lead to the development of new crop varieties and livestock breeds that are more resilient to disease, drought, and other stressors.

In the robotics and automation space, the USDA is funding research into the use of drones and other autonomous technologies for agriculture. These technologies can be used to collect data on crops and livestock, monitor soil conditions, and apply pesticides and fertilisers more precisely, which can improve yields and reduce environmental impact.

In relation to soil quality, the USDA is funding research into the microbiome - the complex community of microorganisms that live in soil, plants, and animals. Understanding how these microorganisms interact with their hosts can lead to new insights into how to improve crop yields, promote animal health, and reduce the use of antibiotics in livestock production.

According to the USDA 2022 Agency Financial report, a total of 2,962,000,000USD was spent by the Agency on R&D:

Research and Development:

Agricultural Research Service		
Human Nutrition	\$	122
New Products/Product Quality/Value Added		127
Livestock Production		135
Crop Production		325
Food Safety		121
Livestock Protection		144
Crop Protection		235
Environmental Stewardship		272
National Bio and Agro-Defense Facility		120
National Institute of Food and Agriculture		
Land-grant University System		974
Forest Service		272
Economic Research Service		
Economic and Social Science		89
National Agricultural Statistics Service		
Statistical		11
Natural Resources Conservation Service		
Plant Materials Centers		12
Soil Survey Research		3
Total Research and Development	\$	2,962

Table 3: USDA R&D expenditure FY2022

(Source: [USDA.gov](https://www.usda.gov))

There is little information on the R&D applications in the above listed categories, and the current published [Research, Education and Economics Action Plan](#) for the agency is from 2012. However, the structure of the agency provides further insight into how their R&D investments are focused on a general scientific area, for example Artificial Intelligence (AI) rather than the application of that innovation, for example using AI to monitor soil quality. This can be demonstrated by the research institutes which the USDA has funded in the area of AI, noting that investment in this broad area of science, “promises personalized healthcare; enhanced national security; improved transportation; more effective education, and precision agriculture, to name just a few benefits. Development of AI technologies has the potential to improve commerce, manufacturing, logistics, medicine, and agriculture” (<https://www.nifa.usda.gov/grants/funding-opportunities/artificial-intelligence-ai-research-institutes>).

Through looking at the funding patterns of both DARPA and USDA over a 20 year period we are able to ascertain shifts in their focus areas and how such technologies are being filtered into other industries. This approach remains true to both agencies missions which are focused on funding transformational innovation. By conducting a review of both agencies’ annual reports and strategic documents, we have been able to determine areas of investment over time and how these have evolved and continue to change within both agencies (sources consulted are available at <https://www.darpa.mil/about-us/budget> and <https://www.usda.gov/media/agency-reports> and <https://www.nifa.usda.gov/about-nifa/what-we-do>).

DARPA's investment budget has remained relatively consistent over the last two decades, with an annual budget of approximately three billion USD per year:

- From 2002 to 2006, DARPA's funding was primarily focused on **information technology**, including cybersecurity and information processing.
- In 2007, DARPA shifted its focus to **robotics and autonomous systems**, with a particular emphasis on unmanned aerial vehicles (UAVs) and ground-based robots. The agency's funding for these areas continued to increase through to 2014.
- From 2015 to 2018, DARPA shifted its focus to **biological technologies**, including gene editing, synthetic biology, and advanced prosthetics. This focus on biotechnology continued into 2019 and 2020, with an increased emphasis on **neuroscience and neurotechnology**.

Unlike the DARPA budget, the USDA's budget has fluctuated over the last 20 years. The average USDA funding budget over the last 20 years (fiscal years 2002-2021) is approximately \$119.7 billion per year. The USDA's budget can fluctuate significantly from year to year depending on a variety of factors, such as changes in national priorities, economic conditions, and political circumstances. Some notable changes in budget can be attributed to the need for innovation in specific areas, for example:

- FY 2006: budget increased to \$88.2 billion, in part due to increased funding for **biofuels research and renewable energy**;
- FY 2007, budget increased again to \$92.4 billion, with continued emphasis on **renewable energy research**;
- FY 2012, the USDA's budget decreased (from FY 2011) to \$144.5 billion, with increased emphasis on **climate change research**;
- FY 2014, the USDA's budget increased to \$156.2 billion, with an emphasis on **rural development**;
- FY 2017, the USDA's budget increased slightly to \$146.8 billion, with an emphasis on **agricultural research**;
- FY 2019, the USDA's budget increased to \$153.5 billion, with **continued emphasis on agricultural research**;
- FY 2020, the USDA's budget increased to \$161.0 billion, in part due to **COVID-19 relief efforts**.

Considering the links from agriculture to horticulture, we provide a further look at changes in investment by the USDA over a 20-year fiscal period (to 2020 based on available reporting figures):

- From 2002 to 2005, USDA's funding was focused on **agricultural research**, with an emphasis on developing new crop varieties and improving crop yields.
- In 2006 and 2007, the agency's funding shifted to **renewable energy**, including biofuels and biomass research.
- From 2008 to 2011, USDA's funding focused on **food safety and nutrition**, with an emphasis on reducing foodborne illnesses and improving the nutritional content of foods.
- In 2012 and 2013, the agency's funding shifted to **climate change research**, with a focus on developing strategies for mitigating the effects of climate change on agriculture.
- From 2014 to 2017, USDA's funding focused on **rural development**, including support for small businesses and rural infrastructure projects.
- In 2018 and 2019, the agency's funding shifted back to **agricultural research**, with an emphasis on improving crop yields and developing new crop varieties.
- In 2020, USDA's funding shifted to **COVID-19 relief efforts**, with a focus on supporting farmers and rural communities affected by the pandemic.

Overall, the funding patterns of DARPA and USDA have varied over the past 20 years, reflecting changes in national priorities and emerging technologies. Both agencies have demonstrated a commitment to supporting research and development in areas that have the potential to benefit society and innovate outside their agency areas of defence and agriculture.

US National Science Foundation (NSF) as another player

One example of cutting edge research and development supported by the US National Science Foundation: Agriculture = 3349 patents

The highly cited recent patents give a guide to the cutting edge work funded by NSF

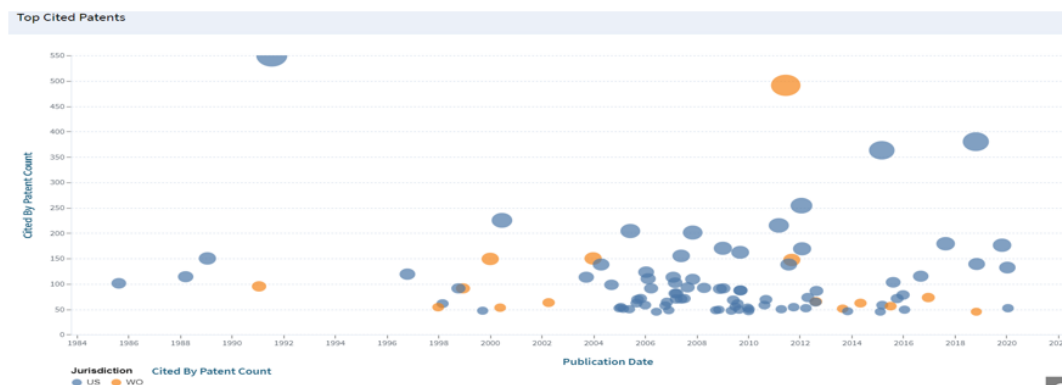


Figure 11: NSF Patents

Source:

[https://www.lens.org/lens/search/patent/analysis?q=\(%22national%20science%20foundation%22\)%20AND%20%22agriculture%22&p=0&n=10&s=_score&d=%2B&f=false&e=false&l=en&authorField=author&dashboardId=13358&dateFilterField=publishedYear&orderBy=%2B_score&presentation=false&previe w=true&stemmed=true&useAuthorId=false](https://www.lens.org/lens/search/patent/analysis?q=(%22national%20science%20foundation%22)%20AND%20%22agriculture%22&p=0&n=10&s=_score&d=%2B&f=false&e=false&l=en&authorField=author&dashboardId=13358&dateFilterField=publishedYear&orderBy=%2B_score&presentation=false&previe w=true&stemmed=true&useAuthorId=false)

Major industry players leading the way

One example of cutting edge research and development supported by industry: Agriculture = 950,000 patents

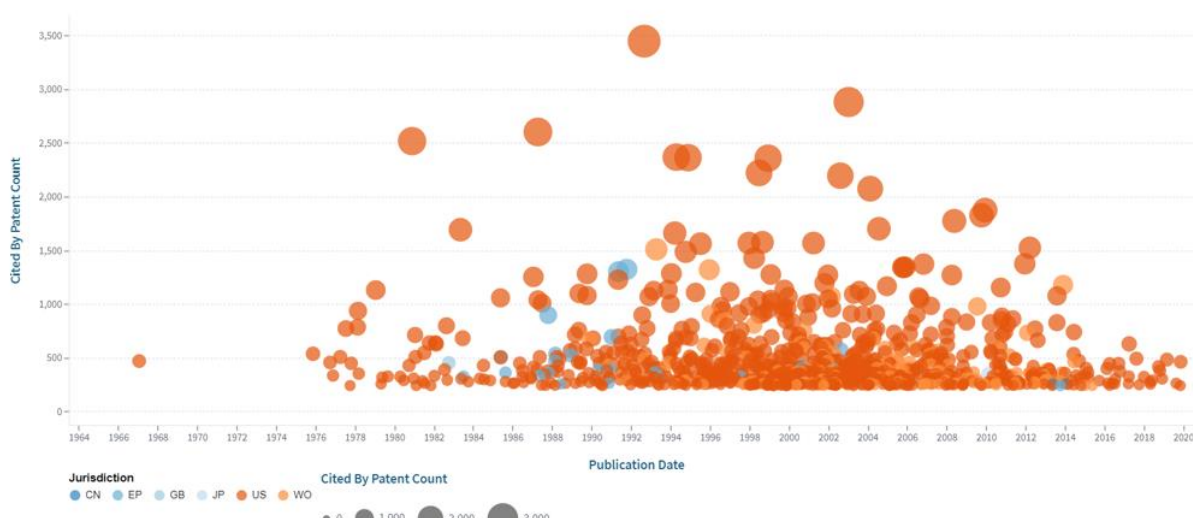


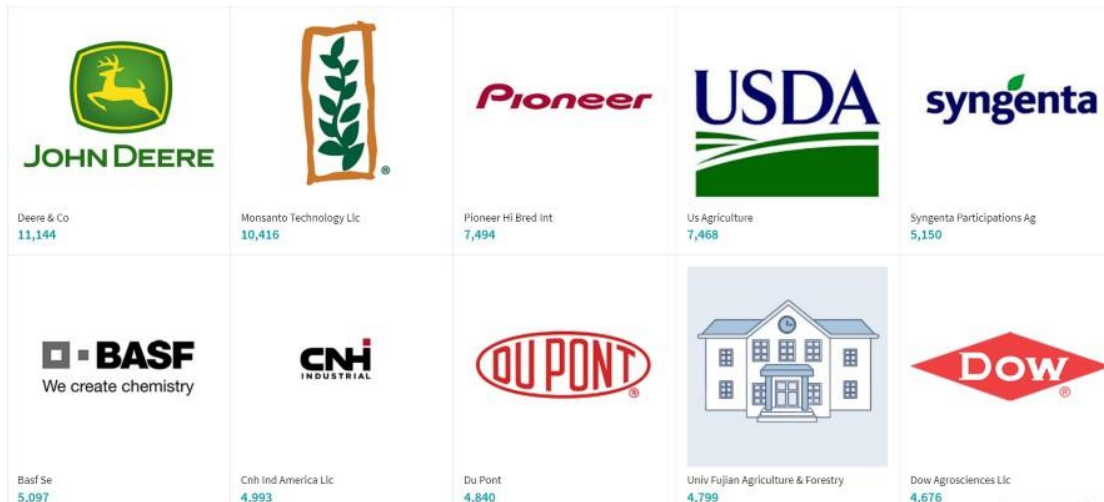
Figure 12: Agriculture industry patents

Source:

https://www.lens.org/lens/search/patent/analysis?q=%22agriculture%22&p=0&n=10&s=_score&d=%2B&f=false&e=false&l=en&authorField=author&dashboardId=13358&dateFilterField=publishedYear&orderBy=%2B_score&presentation=false&preview=true&stemmed=true&useAuthorId=false

Who is leading agriculture?

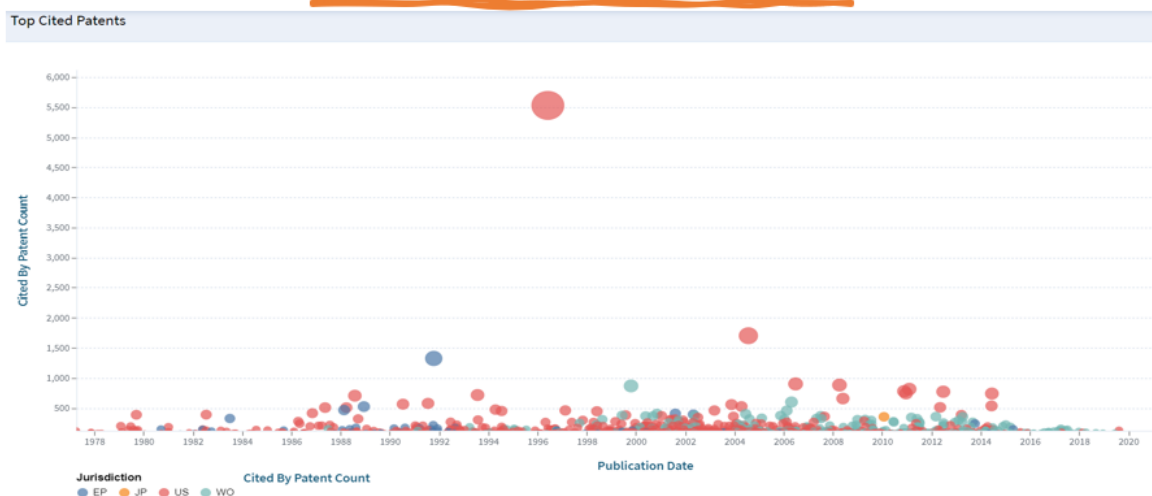
Agriculture patent applicants – leading organisations



If we go to the link (now or in the afternoon session) we can drill down to the strongest recent efforts:
https://www.lens.org/lens/search/patent/analysis?q=%22agriculture%22&p=0&n=10&s=_score&d=%2B&f=false&e=false&l=en&authorField=author&dashboardId=13358&dateFilterField=publishedYear&orderBy=%2B_score&presentation=false&preview=true&stemmed=true&useAuthorId=false

Figure 13: Leading patent applicants**Who is leading horticulture?**

One example of cutting edge research and development supported by industry: Horticulture = 108,806 patents

**Figure 14: Horticulture patents**

Source:

https://www.lens.org/lens/search/patent/analysis?q=%22horticulture%22&p=0&n=10&s=_score&d=%2B&f=false&e=false&l=en&authorField=author&dashboardId=13358&dateFilterField=publishedYear&orderBy=%2B_score&presentation=false&preview=true&stemmed=true&useAuthorId=false

Horticulture patent applicants – 108,000 patents

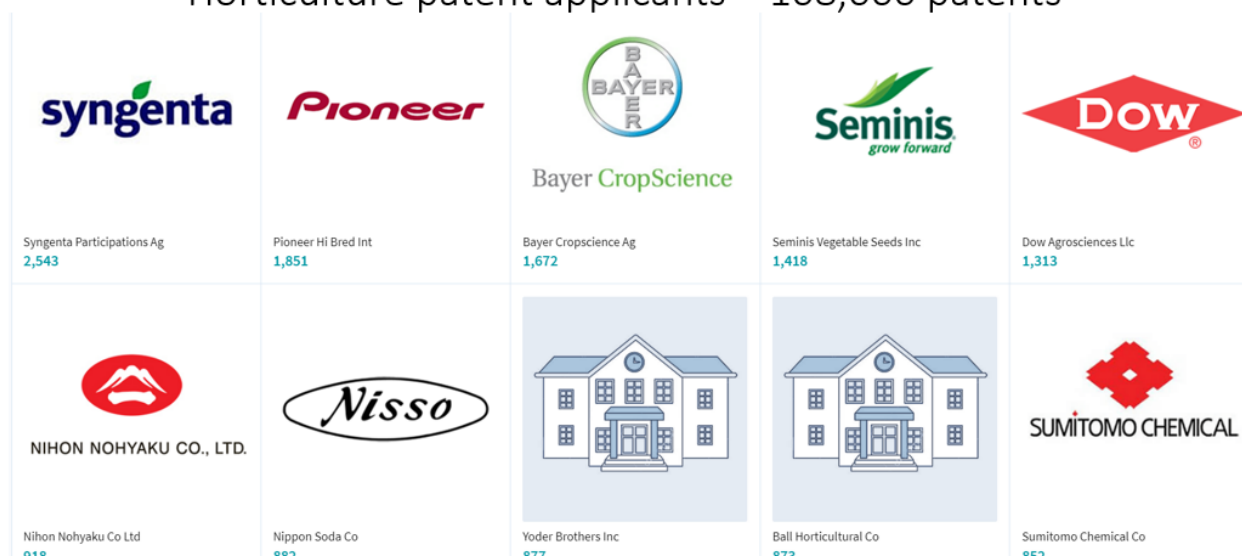


Figure 15: Hort patent applicants

Source:

https://www.lens.org/lens/search/patent/analysis?q=%22horticulture%22&p=0&n=10&s=score&d=%2B&f=false&e=false&l=en&authorField=author&dashboardId=13358&dateFilterField=publishedYear&orderBy=%2B_score&presentation=false&preview=true&stemmed=true&useAuthorId=false

Exports as an R&D driver

Export focussed industries are often the most competitive, have the highest R&D expenditure to achieve and maintain competitiveness for those countries and companies at or near the top of the league ladder, and therefore operate closer to the cutting edge than those focussed on a domestic market.

Based on the most recent available aggregated data from the Food and Agriculture Organisation of the United Nations (FAO), the world's most exported horticultural crops by value in USD for the year 2020 were:

- **Fresh fruits:** Fresh fruits were the most exported horticultural crop by value, with a total export value of \$100.2 billion in 2020. The top exporting countries of fresh fruits were China, the United States, and Chile.
- **Vegetables:** Vegetables were the second most exported horticultural crop by value, with a total export value of \$68.4 billion in 2020. The top exporting countries of vegetables were China, the United States, and Mexico.
- **Cut flowers:** Cut flowers were the third most exported horticultural crop by value, with a total export value of \$20.5 billion in 2020. The top exporting countries of cut flowers were the Netherlands, Colombia, and Ecuador.
- **Edible nuts:** Edible nuts were the fourth most exported horticultural crop by value, with a total export value of \$17.3 billion in 2020. The top exporting countries of edible nuts were the United States, Vietnam, and India.
- **Spices:** Spices were the fifth most exported horticultural crop by value, with a total export value of \$15.3 billion in 2020. The top exporting countries of spices were India, Vietnam, and Indonesia.

Comparatively, based on the most recent available aggregated data from the FAO, the worlds most exported horticultural crops by volume in USD for the year 2020 were:

- **Fresh vegetables:** Fresh vegetables were the most exported horticultural crop by volume, with a total export volume of 142.5 million tonnes in 2020. The top exporting countries of fresh vegetables were Spain, Mexico, and China.
- **Fresh fruits:** Fresh fruits were the second most exported horticultural crop by volume, with a total export volume of 92.1 million tonnes in 2020. The top exporting countries of fresh fruits were Ecuador, Costa Rica, and Mexico.
- **Cut flowers:** Cut flowers were the third most exported horticultural crop by volume, with a total export volume of 4.4 million tonnes in 2020. The top exporting countries of cut flowers were Colombia, Ecuador, and the Netherlands.
- **Potatoes:** Potatoes were the fourth most exported horticultural crop by volume, with a total export volume of 21.7 million tonnes in 2020. The top exporting countries of potatoes were France, the Netherlands, and Egypt.
- **Onions:** Onions were the fifth most exported horticultural crop by volume, with a total export volume of 7.6 million tonnes in 2020. The top exporting countries of onions were India, the Netherlands, and China.

The above information has been accessed through the FAO's statistical portal (<https://www.fao.org/faostat/en/#data/TCL>), which provides global export information. It is interesting to note that higher value crops such as spices and nuts do not feature in the list of highest exported products by volume, instead being replaced with lower valued crops such as potatoes and onions.

R&D among highly exported crops

Expenditure on R&D typically has a strong correlation with the global competitiveness and growth of an industry. The value, volume, and compound annual growth rates (CAGR) for each of the top ten tropical and subtropical horticulture crops are provided below based on data from the Food and Agriculture Organization (FAO) and other sources:

Crop	Production Value (USD B)	Volume (M Tonnes)	CAGR %
Bananas	14	17.5	3.5
Pineapple	2.5	2.9	6.7
Avocado	2.8	7.9	10.3
Mango	2.2	1.1	4.9
Papayas	0.871	0.998	2.7
Guavas	0.112	0.198	5.5
Passionfruit	0.148	0.108	2.1
Coconuts	4.6	10.9	2.8
Cashew nuts	1.4	0.791	4.1
Lychees	0.317	0.223	8.1

Table 5: Value, volume and CAGR of top global export performers

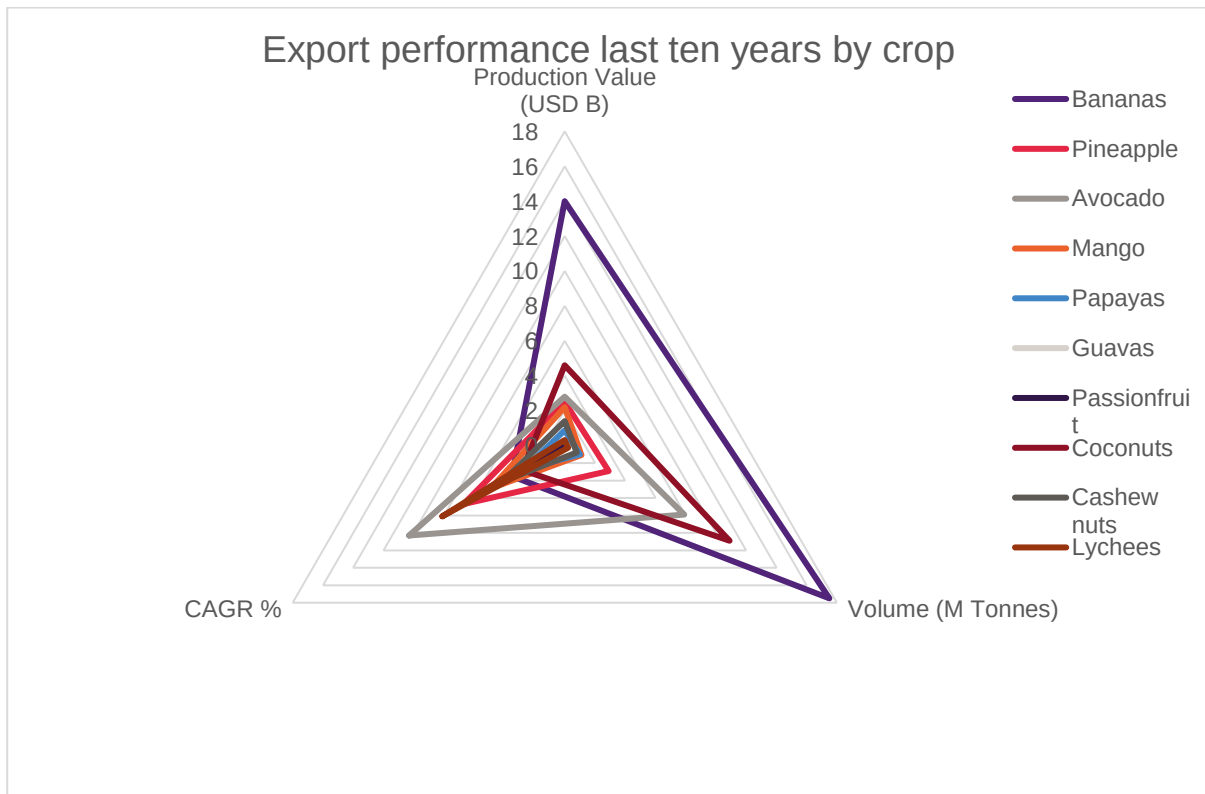


Figure 16: Value, volume and CAGR of top global export performers

Related to global trade performance is expenditure on R&D to capture or maintain competitiveness. Again using patents as a proxy for we can look at the two highest value export crops, bananas and avocados.

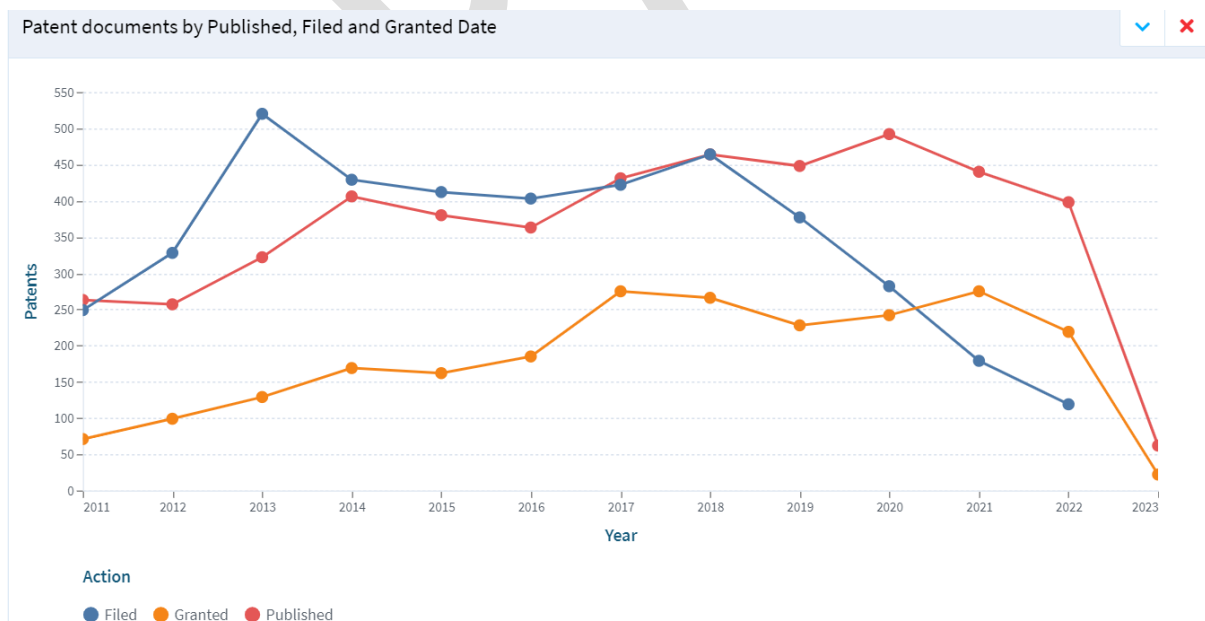


Figure 17: Avocado patents from 2010 = 4975

Patent documents by Published, Filed and Granted Date

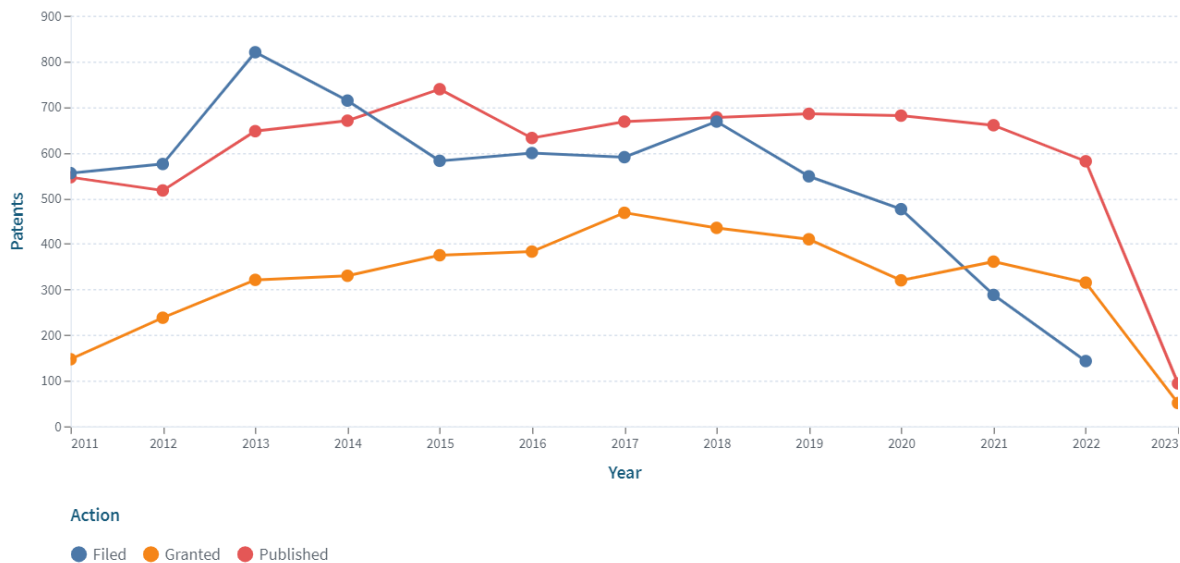


Figure 18: Banana patents from 2010 = 8294

In contrast, cashews are declining in production volume, partly because of senescence and the high labour costs of harvesting and processing. Limited co-production from the cashew fruit, such as for beverages and food supplements, also affects the viability of the crop.

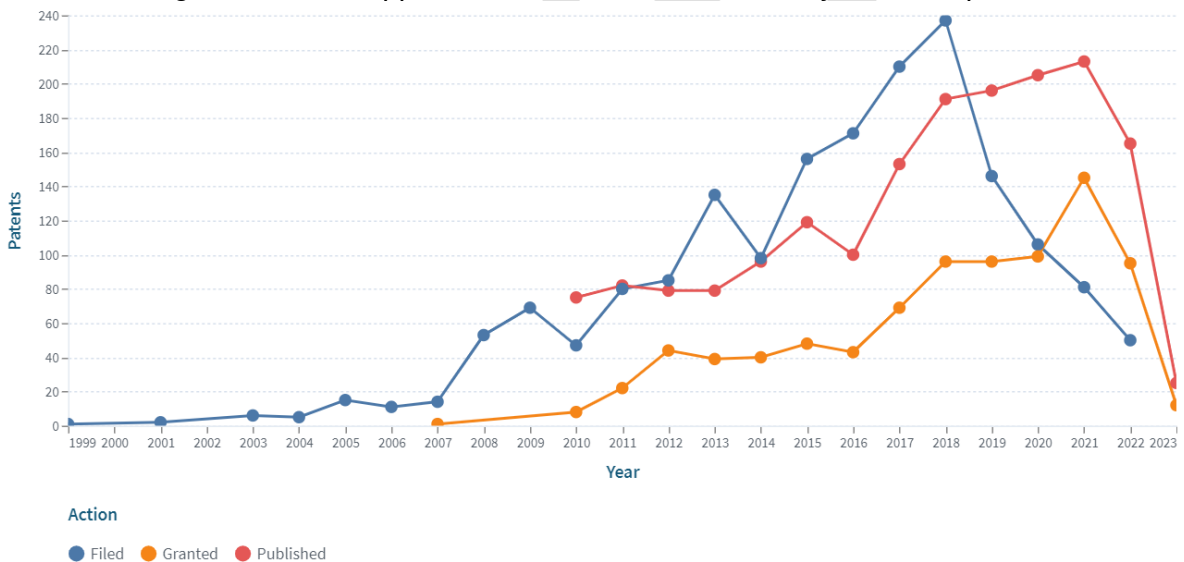


Figure 19: Cashew patents from 2010 = 1778

Despite the apparent market decline, patents related to cashews have picked up in recent years, with Syngenta and CSIRO figuring prominently, with their patents relating strongly to the production of fatty acids and genetic engineering.

Top Applicants				
Syngenta Participations Ag 307	Commw Scient Ind Res Org 162	Sumitomo Chemical Co 82	Syngenta Crop Protection Ag 81	Singh Surinder Pal 72
Grains Res & Dev Corp 70	Pioneer Hi Bred Int 60	Petrie James Robertson 59	Fmc Corp 51	Bayer Cropscience Ag 47

Figure 20: Cashew patent applicants

Appendix 1.

Codes in order of vertical axis listing in Table 1: Patent heatmap, horticulture landscape over the last 20 years (generated February 2023)

Source: <https://www.uspto.gov/web/patents/classification/cpc/html/cpc.html>

Note: When looking at the codes, the more letters and numbers in the code the more specific the subcategory in which the patent has been attributed to.

CPC Code	Title (and any relevant notes according to the patent listing)
Y10T442	Fabric [woven, knitted, or nonwoven textile or cloth, etc.]
H01L33	Semiconductor devices with at least one potential-jump barrier or surface barrier specially adapted for light emission; Processes or apparatus specially adapted for the manufacture or treatment thereof or of parts thereof. Note: This group covers light-emitting diodes [LED] or super luminescent diodes [SLD], which emit visible light, infrared [IR] light or ultraviolet [UV] light.
G16H50	ICT specially adapted for medical diagnosis, medical simulation or medical data mining; ICT specially adapted for detecting, monitoring or modelling epidemics or pandemics
G06V10	Arrangements for image or video recognition or understanding
G06N3	Computing arrangements based on biological models Note: This group could include, Biomolecular computers, i.e. using biomolecules, proteins, cells using DNA, cells using neurons, Artificial life; i.e. computing arrangements simulating life; based on simulated virtual individual or collective life forms, e.g. social simulations or particle swarm optimisation [PSO]; based on physical entities controlled by simulated intelligence so as to replicate intelligent life forms, e.g. based on robots replicating pets or humans in their appearance or behaviour; Neural networks; Architecture, e.g. interconnection topology.
G01S17	Systems using the reflection or reradiation of electromagnetic waves other than radio waves, e.g. lidar systems Note: This group covers, systems for detecting the presence of an object, e.g. by reflection or reradiation from the object itself, or from a transponder associated with the object, for determining the distance or relative velocity of an object, for providing a coordinated display of the distance and direction of an object or for obtaining an image thereof;

	systems arranged for mounting on a moving craft or vehicle and using the reflection of waves from an extended surface external to the craft, e.g. the surface of the earth, to determine the velocity and direction of motion of the craft relative to the surface.
G01J3	Spectrometry; Spectrophotometry; Monochromators; Measuring colours
F24F11	Control or safety arrangements Note: This group relates to the temperature, pressure and humidification of air in a room/space.
F21W2131	Use or application of lighting devices or systems not provided for in codes F21W 2101/00-F21W 2121/00 Note: This is a large category which includes the use of lighting in a myriad of settings including indoor, outdoor, equipment, buildings, furniture and structures.
F21V29	Protecting lighting devices from thermal damage; Cooling or heating arrangements specially adapted for lighting devices or systems
F21V23	Arrangement of electric circuit elements in or on lighting devices
F21V21	Supporting, suspending, or attaching arrangements for lighting devices
D21H17	Non-fibrous material added to the pulp, characterised by its constitution; Paper-impregnating material characterised by its constitution Note: This large category includes the use of the following in paper or pulp, microorganisms and enzyme use, waste products, non-macromolecular organic compounds, Nitrogen-containing compounds, polyamides, waxes and many others.
D04H3	Non-woven fabrics formed wholly or mainly of yarns or like filamentary material of substantial length
C40B40	Libraries per se, e.g. arrays, mixtures Note: This category contains Libraries contained in or displayed by microorganisms, e.g. bacteria or animal cells; Libraries contained in or displayed by vectors, e.g. plasmids; Libraries containing only microorganisms or vectors and other libraries made up of various biological compounds.
C12M43	Combinations of bioreactors or fermenters with other apparatus Note: As an example, this category includes bioreactors and fermenters combined with devices for liquid fuel extraction e.g.: biorefineries.
C10L5	Solid fuels (produced by solidifying fluid fuels)
C10G2300	Aspects relating to hydrocarbon processing covered by groups C10G 1/00 - C10G 99/00 Note: This category includes hydrocarbon processed items such as feedstock, waste, biomass, natural gas and various oils.
C08F8	Chemical modification by after-treatment (graft polymers, block polymers, crosslinking with unsaturated monomers or with polymers C08F 251/00 - C08F 299/00 ; of conjugated diene rubbers C08C)

C08F22	Homopolymers and copolymers of compounds having one or more unsaturated aliphatic radicals each having only one carbon-to-carbon double bond, and at least one being terminated by a carboxyl radical and containing at least one other carboxyl radical in the molecule; Salts, anhydrides, esters, amides, imides or nitriles thereof
C07K2317	Immunoglobulins specific features Note: this category covers immunoglobins isolated from numerous sources including eggs, milk and plants.
C07C335	$\begin{array}{c} \text{S} \\ \\ >\text{N}-\text{C}-\text{N}< \end{array} \quad \text{or} \quad \begin{array}{c} \text{S}- \\ \\ -\text{N}=\text{C}-\text{N}< \end{array}$ Thioureas, i.e. compounds containing any of the groups , the nitrogen atoms not being part of nitro or nitroso groups
C04B35	Shaped ceramic products characterised by their composition {(porous ceramic products C04B 38/00 ; ceramic articles characterised by particular shape, see the relevant classes, e.g. linings for casting ladles, tundishes, cups or the like B22D 41/02 ; ceramic substrates for microelectronic semi-conductors H01L 23/15); Ceramics compositions (containing free metal bonded to carbides, diamond, oxides, borides, nitrides, silicides, e.g. cermets, or other metal compounds, e.g. oxynitrides or sulfides other than as macroscopic reinforcing agents C22C ; {shaping of ceramics B28B }); Processing powders of inorganic compounds preparatory to the manufacturing of ceramic products {(chemical preparation of powders of inorganic compounds C01 ; infiltration of sintered ceramic preforms with molten metal C04B 41/51)}
B65D25	Details of other kinds or types of rigid or semi-rigid containers
B65D11	{Containers having bodies formed by interconnecting or uniting two or more rigid, or substantially rigid, components made wholly or mainly of plastics material (specially constructed to be opened by cutting, piercing, or tearing of wall portions B65D 17/00 ; pallets B65D 19/00)}
B65D1	Containers having bodies formed in one piece, e.g. by casting metallic material, by moulding plastics, by blowing vitreous material, by throwing ceramic material, by moulding pulped fibrous material, by deep-drawing operations performed on sheet material (by winding, bending, or folding paper B65D 3/00 , B65D 5/00 ; specially constructed to be opened by cutting, piercing, or tearing of wall portions B65D 17/00 ; pallets B65D 19/00 ; details of bottles or of jars B65D 23/00 ; bundles of articles held together by packaging elements for convenience of storage or transport, e.g. portable segregating carriers for plural receptacles such as beer cans, pop bottles, B65D 71/00)
B65B5	Packaging individual articles in containers or receptacles, e.g. bags, sacks, boxes, cartons, cans, jars

B65B43	Forming, feeding, opening or setting-up containers or receptacles in association with packaging (forming pockets in sheets, blanks or webs, by pressing the material into forming dies or moving it through folding dies B65B 47/00)
B65B13	Bundling articles Note: This group contains patents such as, applying and securing binding material around articles or groups of articles, e.g. using strings, wires, strips, bands or tapes.
B33Y10	Processes of additive manufacturing
B32B38	Ancillary operations in connection with laminating processes
B32B37	Methods or apparatus for making layered products; Treatment of the layers or of the layered products Note: for example, laminating, bonding, adhesives.
B32B3	Layered products comprising a layer with external or internal discontinuities or unevennesses, or a layer of non-planar form (fibrous or filamentary layer B32B 5/02 ; particulate layer B32B 5/16 ; foamed layer B32B 5/18); Layered products having particular features of form (receptacles or tubular products B32B 1/00)
B32B2262	Composition or structural features of fibres which form a fibrous or filamentary layer or are present as additives Note: this includes such categories as vegetal fibres like cellulose cotton, wood fibres and also polyamide fibres.
B32B2255	Coating on the layer surface
B32B2250	Layer arrangements; Coating, impregnation or embedding of layers; Composition of fibres, particles or foam present on a layer; Resin or rubber layer containing a blend of polymers or recycled material
B25J9	Programme-controlled manipulators Note: this category includes such items as home robots – small robots for domestic use, exoskeletons, kinematic devices, gantry devices and conveyor devices.
B07B13	Grading or sorting solid materials by dry methods, not otherwise provided for; Sorting articles otherwise than by indirectly controlled devices
B05B9	Spraying apparatus for discharge of liquids or other fluent material, without essentially mixing with gas or vapour
B01J2219	Chemical, physical or physico-chemical processes in general; Their relevant apparatus Note: this includes such large areas as chemical plants, industrial plants and pilot-scale plants.
B01F27	Mixers with rotary stirring devices in fixed receptacles (magnetic mixers B01F 33/45); Kneaders
A61B5	Measuring for diagnostic purposes (radiation diagnosis A61B 6/00 ; diagnosis by ultrasonic, sonic or infrasonic waves A61B 8/00); Identification of persons Note: as an example, this category includes devices such as those used for remote monitoring of patients using telemetry. Many of the items are linked to medical use devices such as for the measurement or transmission of ECG, EEG, foetal or obstetric data.

A61B2562	Details of sensors; Constructional details of sensor housings or probes; Accessories for sensors
A61B17	Surgical instruments, devices or methods, e.g. tourniquets (A61B 18/00 takes precedence; contraceptive devices, pessaries, or applicators therefor A61F 6/00 ; eye surgery A61F 9/007 ; ear surgery A61F 11/00)
A23L27	Spices; Flavouring agents or condiments; Artificial sweetening agents; Table salts; Dietetic salt substitutes; Preparation or treatment thereof
A01N29	Biocides, pest repellants or attractants, or plant growth regulators containing halogenated hydrocarbons
A01D45	Harvesting of standing crops (A01D 44/00 takes precedence; threshing machines adapted for special crops, threshing devices for combines adapted for special crops A01F 11/00 ; harvesting of mushrooms A01G 18/70)
A01B1	Hand tools (edge trimmers for lawns A01G 3/06 {; machines for working soil A01B 35/00 ; making hand tools B21D {})

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CRICOS Provider Number 00025B



Lean design workshop pilot: Identifying Transformational R&D Opportunities for the Tropical and Subtropical Horticulture Industry

Final Report
04.04.23
V2

A strategic partnership between:

**Hort
Innovation**

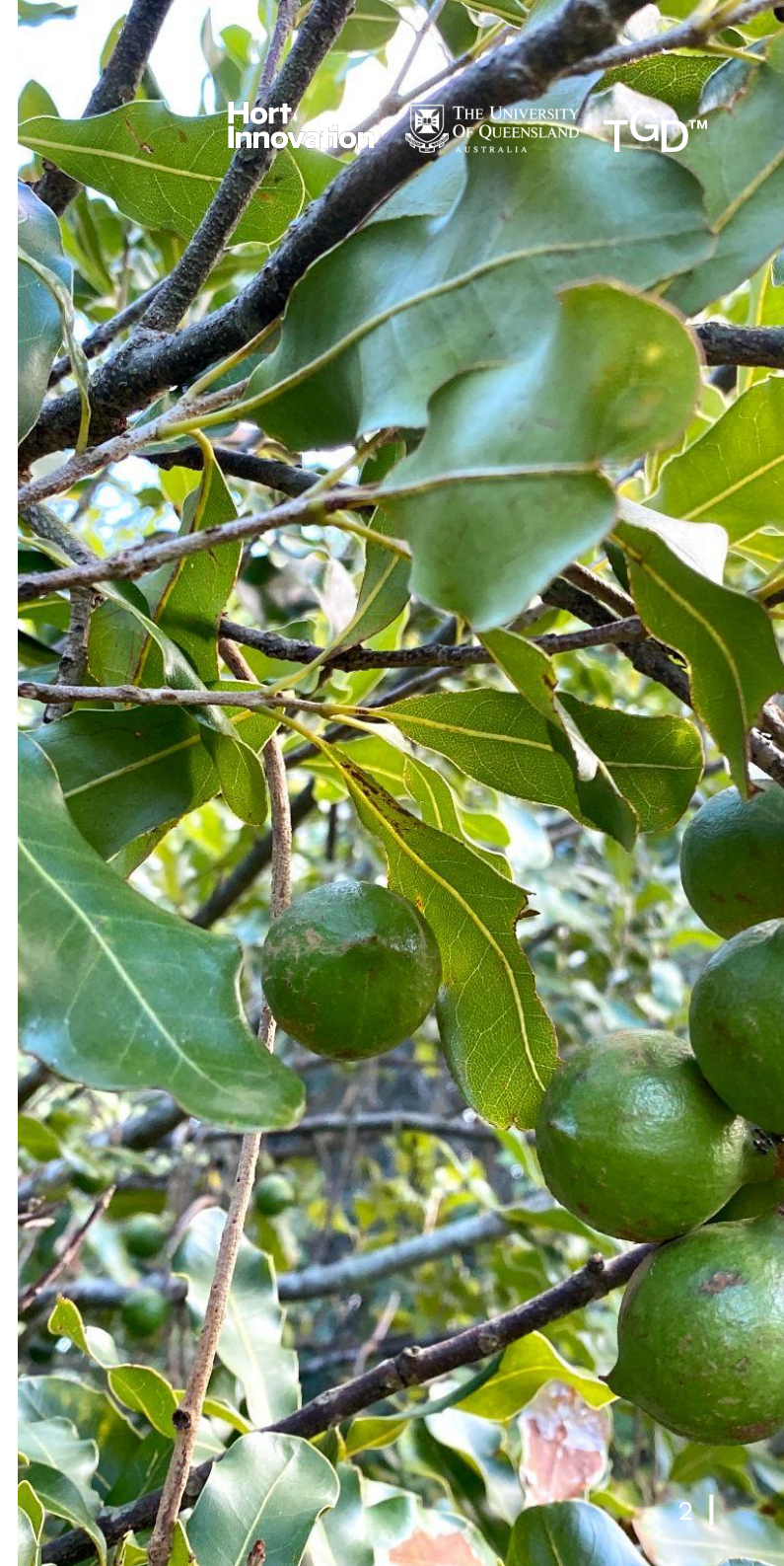


In collaboration with:

TheGrowthDrivers™

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Executive Summary

The purpose of this project was to pilot how a lean design approach could be used to explore challenges and opportunities that tropical and subtropical horticulture will face over the next 5-10 years, and identify the transformational research and development required to ensure long-term sustainability and global competitiveness of the industry.

The project team conducted a series of stakeholder engagement activities, including a survey, eleven interviews, and a workshop, to identify crop specific and industry-wide challenges and opportunities. The desired outputs from this project were:

1. A lean design process implemented to identify challenges and opportunities for tropical and subtropical horticulture for transformational benefit to tropical and subtropical horticulture industries.
2. High-priority recommendations for tackling the challenges and opportunities in tropical and subtropical horticulture are provided.
3. Identified challenges and opportunities for tropical/subtropical horticulture, including R&D recommendations, research translation pathways, strategic collaborations, and future investments.

It became apparent after the survey and interviews that stakeholders focus on immediate, 'horizon 1' type challenges instead of transformational changes for long-term prosperity. This provided challenges to the process, and required adaptation in the workshop to ensure useful insights were developed.

While the workshop did help elucidate some transformational opportunities, it reinforced that a different approach to business-as-usual is needed should HIA seek to identify these transformational opportunities again in the future.

A summary of the transformational opportunities identified:

1. **Implement innovative climate resilient production systems (indoors and outdoors)** to enable growers to meet the changing inputs and outputs demands of a future characterised by different consumer preferences and a significantly different climate.
2. **Harness the digital revolution for the benefit of the entire horticulture logistics and supply chain** to improve the efficiency and reduce the environmental impact of the sector, and to secure market access that is based on low-carbon footprint farming.
3. **Build environmentally sustainable crop protection systems** to reduce pesticide use or residue and improve market access.
4. **Build the labour force needed to support the horticulture industry of the future**, and ensure we have the people needed to implement the technologies our farms of the future will use.
5. **Develop new and differentiated products to meet future consumer requirements** and secure domestic and international market access.

In addition to these, three system-level opportunities were also identified:

1. **Create probing systems** to explore innovations in other sectors, to 'leapfrog' the technology adoption curve.
2. **Design unique collaborative structures** to encourage transformational R&D, such as DARPA-lite or DARPA-like.
3. **Set specific tropical and subtropical horticulture targets** to coordinate activities and focus areas.



The Growth Drivers™

Project background

Horticulture Innovation Australia (HIA) is the R&D corporation for the Australian horticulture industry. As a grower-owned corporation, Hort Innovation seeks to provide value to the industry, through conducting research and developing solutions that address market failures. However, this R&D is often focused on delivering incremental change, and at a crop specific level. This R&D usually also requires clear returns on investment, further entrenching research in immediate pains, as opposed to challenges that will be faced in the future (and therefore will have slower and less immediate ROI's). Given the mounting pressures felt across the industry and crop groups, from climate change to growing populations, there is a need to identify opportunities for transformational change, and build momentum around research and solution development that will result in longer-term industry resilience. To support Hort Innovation in exploring this need with industry, a strategic partnership with the University of Queensland was formed.

The University of Queensland (UQ) plays a prominent role in the tropical and subtropical research space. The Queensland Alliance for Agriculture and Food Innovation (QAAFI) is a research institute of the University of Queensland, specialising in tropical and subtropical food and systems research. With a wealth of experience exploring transformational solutions for the industry, the University of Queensland played a critical role in not only managing this project, but providing quantitative research, access to stakeholder networks, and participating and contributing to workshop outputs.

Engagement Summary

Throughout the project, stakeholder activities were adapted to ensure project outputs incorporated different industry and research perspectives, and to create buy-in from key stakeholders when it came to workshop attendance. These research activities are summarised below.

Industry Survey | A survey was developed and circulated to industry. The intention of this survey was to gain an initial understanding and prioritisation of the main challenges facing the tropical and subtropical industry. The questions in this survey asked participants to identify key challenges they were facing in the next 5-10 years, at an industry level and individual business level. Participants were then asked to identify the impact of these challenges, and opportunities for overcoming them. A total of 24 people from the industry responded to the survey.

1-on-1 Interviews | Originally focus groups were planned as a follow-up to the survey. However, upon reflection regarding the best way to uncover deep insights from major industry stakeholders, and from connections with these representatives, the project team pivoted to interviews with both researchers and industry representatives. These interviews deep dived into crop specific needs, and built upon survey findings regarding overarching future challenges and opportunities. These interviews also provided the project team with a high-level understanding of the main areas specific crops were researching and investing in. Interviewees also highlighted barriers to achieving research impact in the industry, from siloed projects, to effective solutions struggling to receive funding for commercialisation.

Quantitative Research | To provide a quantitative lens to the project findings, and support the design and delivery of the industry workshop, Prof Hine conducted quantitative research into innovation trends in horticulture and analogous industries. This research identified that innovation in horticulture is currently years behind developments in other industries, such as the defence and medical industries. However, this provides an opportunity to accelerate transformation in the horticulture industry by adapting and building upon technical gains in other industries.

Industry Workshop | On the 8th of March 2023, a lean design workshop was held at the Long Pocket Research Facility (University of Queensland) bringing together industry and government representatives, and UQ researchers. This workshop brought together the qualitative insights developed through the previous two engagement activities, as well as quantitative research developed by Prof Hine. Participants were guided through activities exploring major challenges and opportunities, as well as future R&D requirements and systemic needs to enable transformational R&D.

Project Timeline.



September, 2022
Project Start.



October, 2022
Challenges and opportunities survey sent to stakeholders.



Nov- December, 2022
1-on-1 interviews with key stakeholders and researchers exploring R&D solutions to solve challenges.



February, 2023
In-person workshop validating identified strategic R&D areas, existing solutions, and exploring future project areas to fill research gaps.



April, 2023
Project conclusion.

01. *Exploration*

01.1 Exploration

Interview & Survey Summary

Overview

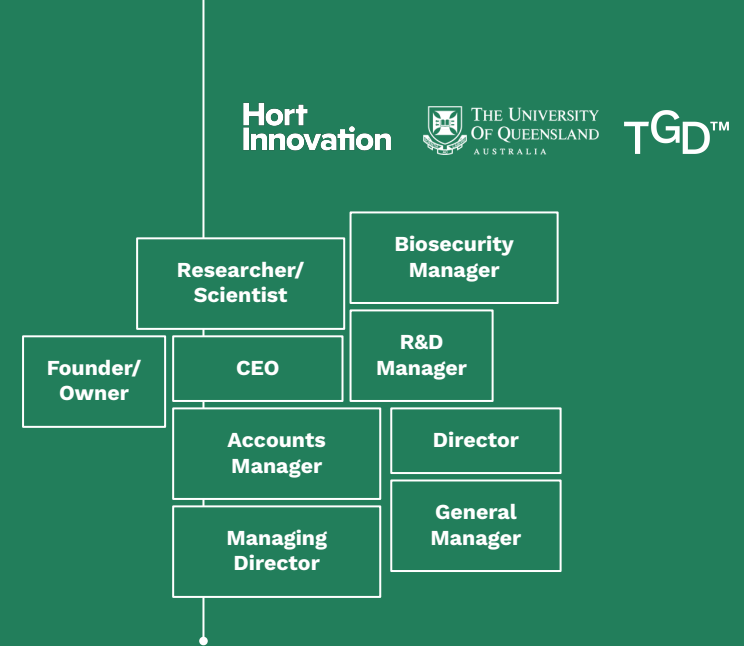
Demographics

The infographic on this page highlights those involved in the survey and interviews, as well as the industries represented. The following pages provide high-level insights outlining both the challenges and opportunities identified through these activities, as well as the systemic findings.

11 Interviews Conducted



23 Survey respondents



Across 20 industries



01.2 Exploration

Workshop Methods

Workshop Overview

The role of The Growth Drivers | The Growth Drivers' (TGD) role in the workshop was to help participants

collaboratively explore the main challenges and opportunities that, if addressed or realised, would result in transformational change in the tropical and subtropical horticulture industry. By asking the right questions, facilitating meaningful conversations and guiding design activities, participants were able to explore this challenging space from a range of angles. These included R&D needs, adoption pathways, and HIA's potential role in facilitating systemic changes.

Stakeholders Involved | Multiple stakeholders across the tropical and subtropical industry and expertise areas were invited to the workshop. The stakeholders invited were either identified by the University of Queensland, or participated in the initial industry survey. Some of the stakeholders' positions included Peak Industry Body CEOs, RD&E Managers, Project Managers, Research Fellows, General Managers and Science Directors. Out of the 43 stakeholders invited, 22 people attended the workshop. There were 25 industry representatives invited, however, many industry stakeholders were unable to attend due to last minute cancellations, conflicts with other events, and the travel required to attend an in-person workshop. Due to these factors, the findings may be limited in depth. Future iterations of this work should seek to include a more representative group of growers and other stakeholders from the industry, and consider alternate engagement formats (e.g. online workshops) to improve attendance. Please refer to Appendix A for the complete participant list.

The following page explores the workshop structure and key sessions.

22

Participants
across...

11

Organisations
exploring...

6

Challenges &
opportunities that
will impact tropical
& subtropical
industries.

Workshop Structure

The workshop commenced with an introduction regarding the project findings so far, quantitative findings from Prof Damian Hine, and an exploration of what transformational R&D is, and tools that can be utilised to identify and tackle transformational opportunities. Following these presentations, participants were guided through four activity sessions. The table below shows the main sessions, and focussing questions explored during the sessions.

Session	Focussing Questions
Presentation: What challenges will we face in 10 years, and how can we overcome them?	<i>What have we discovered so far?</i> <i>What are the quantitative and qualitative findings?</i> <i>What is transformational R&D?</i>
Session 1: Challenge Exploration	<i>What impact will this challenge have if it is not solved?</i> <i>If the challenge is solved, how will it transform the sector?</i> <i>How are stakeholders trying to solve it now & how will they solve it in the future?</i>
Session 2: How do we address these challenges?	<i>How has agriculture innovated previously?</i> <i>What are the main R&D focus areas that will address this challenge?</i> <i>Does technology exist in a parallel industry that we could use to solve this / realise this?</i> <i>If no technology exists, what R&D do we need to invest in to solve / realise this?</i> <i>How do we support the development of these transformational R&D topics?</i>
Session 3: Enabling Solution Adoption	<i>What is the pathway to end-user adoption?</i> <i>What else in the system needs to change to support adoption? E.g. policy? Other technology solutions. New business models?</i>
Session 4: HIA & Supporting Transformational R&D Acceleration	<i>How does HIA support transformational development in R&D in an investment strategy?</i>

What is 'Transformational' R&D

Transformational R&D was defined for the participants, and tools and ways of thinking were identified to support the identification and development of transformational ideas. This was essential for ensuring that participants conducted workshop activities with a 'transformational mindset', continuously interrogating their thinking and ensuring they were exploring opportunities that were 5-10 years away, rather than focusing on immediate challenges. This difficulty in maintaining this future thinking was a challenge throughout stakeholder activities, as stakeholders were often reverting to immediate challenges. "Doing" transformational R&D was defined during the workshop as:

"You identify problems that people have, or opportunities to create a new meaning for people. You build cross-functional teams, set high aspirational goals, validate problems, build a prototype, build-test-learn it to improve, develop a business model (products don't succeed, business models do), launch and scale."

The tools and topics covered throughout this presentation were as follows:

Functional Fixedness	<i>A bias restricting a person's ability to see beyond a tool's intended use, potentially hampering creativity and problem-solving capabilities.</i>
Conceptual Blending	<i>A cognitive process that combines distinct mental spaces to create a new, emergent mental space with novel properties, fostering creativity, problem-solving, and innovation.</i>
Brainstorming	<i>A problem-solving technique that fosters creativity and innovation by generating a large number of ideas in a short amount of time.</i>
Analogous Thinking	<i>Requires finding similarities or connections between seemingly unrelated concepts or domains, to generate new ideas or gain insight.</i>
X Casting	<i>Requires starting with a vision of a desired future state or outcome, and then works backward to identify the necessary steps and conditions needed to achieve that vision. In the context of transformational R&D, backcasting can help to identify and prioritize research areas, technologies, and innovations that have the potential to create significant positive impacts.</i>
Reframing and Recognising Differences	<i>Reframing is the process of changing your perspective on a situation or problem by shifting your mental framework to uncover new possibilities and solutions. Recognising differences means identifying distinctions between things, including appearance, behaviours, values, and beliefs.</i>
Systems Thinking	<i>An approach to problem-solving and decision-making that involves considering the interrelationships and interactions between various elements within a complex system. It involves looking beyond individual components or parts of a system and understanding how they work together to produce a particular outcome or behaviour.</i>

Why do we need 'Transformational' R&D?

Progress and adoption of innovations in tropical and subtropical horticulture were explored and compared to what is happening in other industries.

illustrate patterns in innovation and how innovations in horticulture are often 'borrowed' from other sectors. Sectors such as defence and medical are often hotspots of innovations that over time get tailored and adopted by other sectors, including agriculture. Damien also shared a few more slides that explored:

- The three horizons
- DARPA's approach to R&D
- The patent landscape

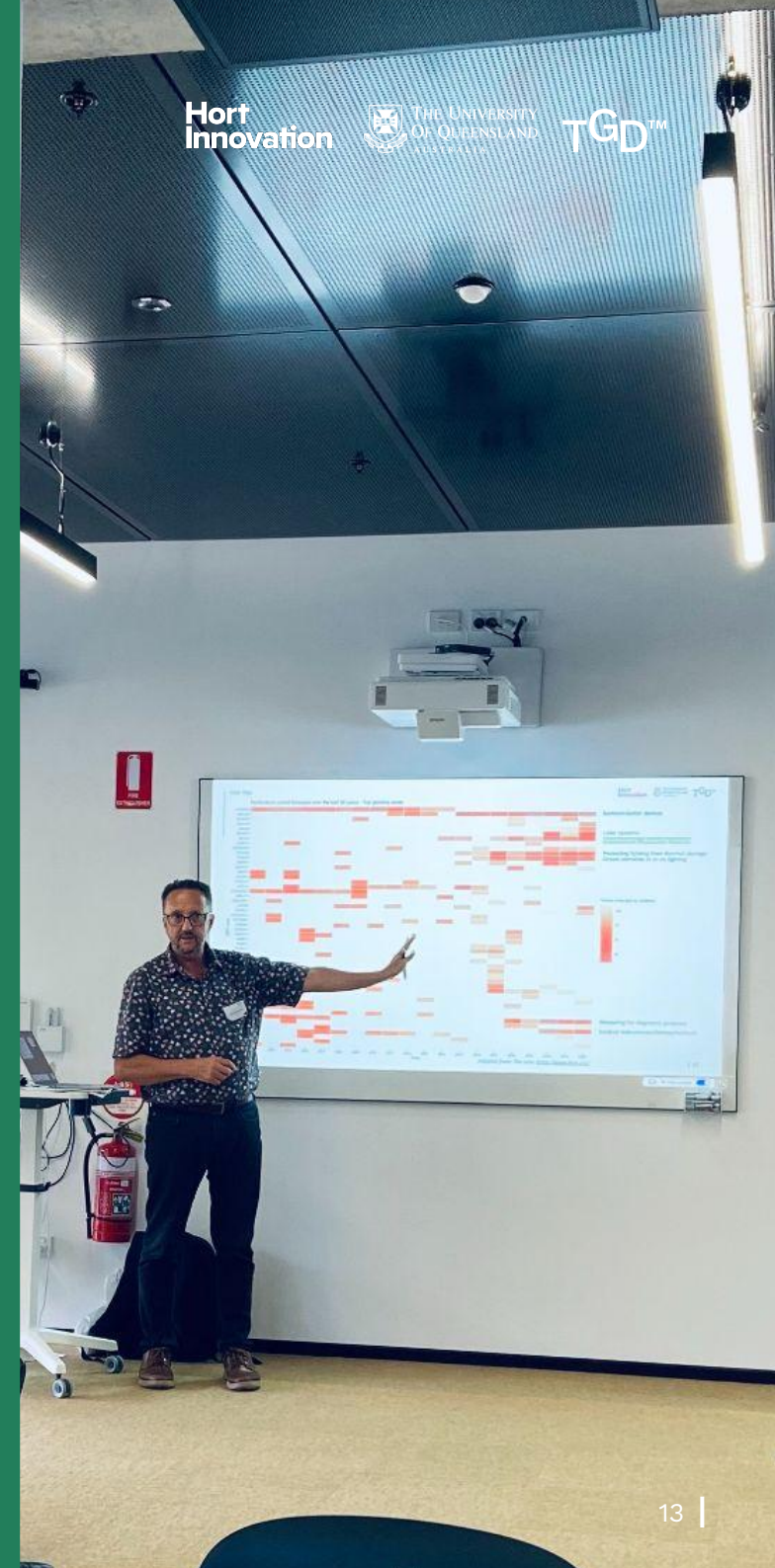
What was said.



"We want to push the boundaries a bit and look ahead. Horizon one looks at what are you doing now, horizon two is still linear, but with Horizon three we are looking for where the technologies are coming from that will disrupt, and if you are ready for those then you are ready to capture those changes."



"We see innovations coming from other industries and the examples given so far have been war and defence - they are big drivers in pest and disease solutions and medicine and all these other areas. But we aren't looking where they come from so we are missing information that we can implement into hort"



02. *Results*

02.1 Results

Challenges & Opportunities

Challenges & Opportunities

The workshop highlighted five key challenges/ opportunities that would transform tropical and subtropical horticulture if addressed or realised, having major implications for the sustainability and prosperity of the industry. These opportunities were:

1. **Implement innovative climate resilient production systems (indoor and outdoor)**
2. **Harness the digital revolution for the benefit of the entire horticulture logistics and supply chain**
3. **Build environmentally sustainable crop protection systems to reduce pesticide use or residue and improve market access**
4. **Build the labour force needed to support the horticulture industry of the future (indoor and outdoor)**
5. **Develop new and differentiated products to meet future consumer requirements and secure domestic and international market access**

The following pages explore the future state if these opportunities are realised, high-level R&D recommendations, and participant-identified research translation pathways.

It is important to note that these five areas, while major challenges to be addressed, are not exhaustive of the challenges/ opportunities that require transformational change. The survey and interviews also highlighted a number of challenges/ opportunities, and while all of these were not explored during the workshop, they are still priorities to be explored in future work.



Implement innovative climate resilient production systems (indoor and outdoor)

01 What's the big challenge/ opportunity that requires industry transformation?

Climate change is already affecting agriculture within Australia and globally, and erratic climatic events are expected to increase over the next decade. A primary characteristic of this change will be a reduction in inputs (including water, fertilisers, pesticides) and an increase in energy costs and land use requirements. Without climate resilient indoor and outdoor crop production systems, climate conditions will dictate which crops can be grown, not growers. Climate will also dictate the quality and quantity of products provided to the market. This could have detrimental effects on prices of products supplied to consumers (and ultimately nutritional value), and increase reliance on imports from countries with more resilient production systems.

02 What will the industry look like if this challenge/opportunity is successfully addressed?

If this challenge is addressed by developing technologies (e.g. new varieties with desired traits, smart propagation tools, predictive breeding programs, smart pre- and post- harvest management tools, improved generation and use of data, and transition to protected cropping (greenhouse and vertical farming)), Australian tropical and subtropical horticultural businesses will be able to produce and supply local and international markets with the products they demand, regardless of the changing climate conditions.

These solutions developed will benefit the industry, the consumers, and reduce environmental impacts.

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03 What R&D needs to be conducted?

- **Explore crop production technologies already developed overseas (e.g. the Netherlands and South Korea),** that improve resource and land use efficiency while integrating zero emissions technologies.
- **Identify tree/ long-term crops that could be targeted for initial solution development.** These crops can provide a testing ground for crops with more complex growing requirements, or environmental challenges (Temperature extremes, pathogen and disease intensifications, flooding, drought, storm etc.).
- **Identify genetic / breeding / propagation work already being undertaken on specific crops,** and gaps in climate resilient breeding research that need to be addressed through R&D investment.

04 What are the research translation pathways?

- **Co-designing solutions with the industry** | Ensuring solutions respond to growers needs and respond to industry sustainability long- and short- term.
- **On-farm demonstrations** | Showing the commercial viability of solutions/ technologies, providing growers with the confidence to invest in and implement solutions.
- **Clear communications** | Providing growers with clear value propositions and business cases to support investment.

Quotes

“This challenge will influence the variety of foods and crops that we will have available, especially if the conditions mean it is much more difficult to grow. Some crops could be extinct in the food supply.”

“Easy crops like tomatoes and cucumbers have been solved... but tree and long term crops are harder to solve... we need to breed crops for protective climates, so we can supply crops independent of climate.”

“We need good infrastructure that is suitable for Australia, not necessarily from Europe.”

Harness the digital revolution for the benefit of the entire horticulture logistics and supply chain

01 What's the big challenge/ opportunity that requires industry transformation?

Australia's large land mass means that the horticulture industry is faced with the challenge of how to transport produce from farms to domestic and international markets, without impacting the quality of produce, in the context of increasing attention paid to 'food miles'.

Over the next 10 years crop production will need to increase to meet local and global growing populations needs. This will increase pressure on transport and logistics systems, and will impact the long-term financial viability of agricultural businesses, primarily due to petrol costs, as well as the environmental sustainability of the industry.

02 What will the industry look like if this challenge/ opportunity is successfully addressed?

If this challenge is addressed, "food miles" will be significantly reduced with production happening closer to consumers through indoor and vertical farming and an optimised supply chain for distant farms. There will be major reductions in the carbon footprint of the industry, and producers/ industries that demonstrate this to consumers will be rewarded a higher price point, as we are seeing in other sectors. There will also be a reduction of waste, with solutions developed that reduce the impact of transport on produce quality. Consumers will therefore have access to consistently locally grown, high-quality and nutritious produce regardless of their location in Australia.

03 What R&D needs to be conducted?

- **Research existing technologies** such as cold chain from pharmaceutical industries and blockchain opportunities. Look at defence and how they manage their complex supply chain requirements, including the use of automation and robotics to improve speed and traceability.
- **Conduct exploratory research into innovative transportation/ delivery/ logistics models** (e.g. Uber, Amazon), and identify learnings that could be applied to the sector.
- **Map current logistics, and identify inefficiencies within the supply chain that targeted interventions can be developed for** (e.g. are there opportunities to reduce travel through centralised locations and collection hubs). There are a growing number AI and machine learning powered technologies used in other sectors, such as defence, to uncover inefficiencies and identify points of weakness. These could be utilised in horticulture to optimise logistics.
- **Optimise AI technologies** to accelerate the development of unmanned indoor and vertical farming through machine learning and logistic optimisation system.

04 What are the research translation pathways?

- **Holistic approach** | Creating clear metrics that demonstrate the overall sustainability of the supply chain to the industry, not just individual components (e.g. packaging) and reduce cost and environmental impact of the entire supply chain.

Quotes

"We need to not follow the US and EU because we are different...We do need a cross pollination of ideas from different industries, for example mining and pharmacy industries...we also need to look at different business models for the supply chain."

"Making ourselves globally competitive and ensuring supply and food security...reducing costs of production...helping with energy issues and the credentials of industry in relation to emissions."

"We need to take a holistic approach, look at the whole supply chain, and ensure the quality of the measures to assess sustainability"

"We always think we can mimic the EU and US, but the distance here is completely different... we need to find our own solutions"

Build environmentally sustainable crop protection systems to reduce pesticide use or residue and improve market access

01 What's the big challenge/ opportunity that requires industry transformation?

With a rapidly changing environment, the threats to our crop production systems posed by pests are increasing both in severity, novelty, and frequency. Growers are faced with the conundrum of needing to increase pesticide usage to deal with these threats to meet increasing production demands, but being pressured by markets to decrease pesticide usage for environmental and health reasons. With market access increasingly based on environmental impact, this threat poses a significant risk to Australia's horticulture system.

As markets shift their requirements to reduced / pesticide free production, there is a growing opportunity for growers in technologically advanced markets to utilise new approaches to capture market opportunities and grow.

02 What will the industry look like if this challenge/ opportunity is successfully addressed?

If this challenge is overcome, growers will have more efficient and resilient production systems, reduced environmental impact, and secured market access to large markets that demand pesticide free / low environmental impact food.

03 What R&D needs to be conducted?

- **Explore biosecurity preparedness opportunities including with neighbouring markets**, to enable our sector to deal with pest threats before they become apparent in Australia and to respond rapidly to them once they enter Australia. Look to AI enabled distributed sensing capabilities to improve how we monitor threats, and invest in capabilities to ensure we have the skills and knowledge needed to address threats when they become apparent.
- **Identify examples of integrated disease management systems** that can be applied broadly across the sector.
- **Identify new biological control and other biopesticide technologies being developed globally**, and invest in piloting these to test utility and adoption readiness in Australian context.
- **Invest in breeding for disease resistance**, to provide growers with pesticide free options for future threats.

04 What are the research translation pathways?

- **Demonstrate value proposition** | Providing growers with a clear understanding of the value proposition and business cases to support investment in new innovations.
- **Smooth transition approaches** | Ensuring that the process of implementation of any new technologies will minimise disruption to existing operations, and therefore, maximise the chance of successful adoption.

Quotes

"Australia has the worst pests at the moment and we use a lot of pesticides in Australia because we have to deal with our pest issues. However, importing countries like China and others are asking for pesticide-free products. This is something we need to solve"

"We should look into native crops that are linked for thousands of years in our climate and have better pest resistance, drought resistance and fire resistance."

"We are looking into pest disease control and risk management, especially regarding fruit flies. This can help open up new markets."

"We're interested in projects looking at breeding and integrated pest management but we don't have the funds to tackle this by ourselves ... this means a lot of large producers are doing their own R&D, with a focus on pest and disease management to increase productivity."

Build the labour force needed to support the horticulture industry of the future (indoor and outdoor)

01 What's the big challenge/ opportunity that requires industry transformation?

The horticulture industry of the future will be highly technology based, utilising machine learning algorithms to support automated production systems, cutting edge disease management systems, highly efficient logistics systems, and transparent market and environmental traceability features.

The tropical and subtropical industry workforce is struggling to meet even today's requirements, both in number and skill set. Without new skilled labour, the ability of growers to adopt new technologies will be limited. This multifaceted labour challenge will have major impacts on production systems, contributing to decreases in the quality of produce (due to harvesting outside of ideal timeframes), and higher levels of waste. If this challenge is not addressed, it will impact the overall food security of Australia.

02 What will the industry look like if this challenge/ opportunity is successfully addressed?

In the future, growers will have access to automation and robotics technologies that allow them to efficiently meet their production system needs (indoor and outdoor), alleviating the need for intensive seasonal labour workforces. Labour will be trained in advanced research and training centers across Australia, on multiple production systems including highly automated greenhouses and vertical farms, as well as task oriented field robots.

03 What R&D needs to be conducted?

- **Explore automation and robotic technologies that have already been developed and used in various other industries**, such as defence and manufacturing, to identify potential applications in horticulture. Look at how they have managed the labour requirements for these technologies.
- **Identifying 'innovators' in the production system** that can be targeted to demonstrate technology adoption and feasibility.
- **Development of research and training centers** that address skills required for operating automated field production as well as advanced indoor and vertical farming systems

04 What are the research translation pathways?

- **Free trials of technology** | Providing the opportunity to test technology and gain buy-in, as well as supporting the development of case studies and cost-benefit analysis to share with growers.
- **Outreach and phased introductions to outline the benefits** | Development of university-led innovation centers where growers can be trained on technology and acquire certification in automation and robotics in horticulture
- **Subscription system** | Offer the opportunity for growers to rent technologies for outdoor farming or greenhouse/vertical farming space to start or transition to advanced farming without the high capital cost.

Quotes

"We are doing things now regarding fruit identification in complex canopies with smart robots, and this also includes canopy management projects with in HIA at the moment."

"With labour and robotics, the technical role in big businesses is always forgotten... if there's a medium size, can you have a graduate to run the robotics? And this could be a major barrier, because there's a lack of technically skilled labour in Agriculture...robots will always need humans in some way."

"It's important to provide information to growers that they can easily interpret."

"We can think about robotics not only during harvest, but also supporting other labour needs (in sheds etc.)."

Develop new and differentiated products to meet future consumer requirements and secure domestic and international market access

01 What's the big challenge/ opportunity that requires industry transformation?

Diverse produce preferences are becoming more and more prevalent in the Australian and international markets and generally, Australia horticulture and other agricultural industries have failed to shift practises/ crop types grown, to capture these markets.

If this challenge is not addressed, Australian horticulture will be less competitive globally, with import competitors more effectively meeting these different demands and flooding the domestic market.

02 What will the industry look like if this challenge/ opportunity is successfully addressed?

By understanding the interaction between diet, health and wellbeing on consumer preferences, growers will be able to capture new markets. Adapting growers regional practises and moving environmentally unsuitable crops indoor, growers will be able to expand their portfolio while securing new local and international markets. This will also provide the industry with the flexibility to continuously adapt to consumer demands, capturing new or expanding current revenue streams.

Consumers in Australia will have more locally grown choice and new varieties of products available to them all year round, as well as higher quality existing varieties independent of seasonality.

03 What R&D needs to be conducted?

- **Conduct market research to understand growing consumer demands**, and new markets that could be captured. This body of research will support growers in making decisions around adopting new and different crops.
- **Develop targeted breeding** to improve climate resilience by improving access to genetics, gene editing, genomics, and breeding technologies targeted toward automation, pest resistance, indoor farming production and climate resilience without compromising sensory and nutritional attributes.
- **Invest in smart propagation technologies** to speed path to market for growers, reducing risks and improving ROI.
- **Explore breeding and processing opportunities** to improve the shelf life of products (e.g. gene - editing to reduce bruising).

04 What are the research translation pathways?

- **Ensuring product development is linked with market development** | Utilising tools such as simulation testing to continuously ensure solutions in development meet market needs and preferences.
- **Feeding down rather than pushing up new products** | Support the market success of new varieties or crops through targeting restaurants and reality programs, building consumer market buy-in and appetite.

Quotes

“We want to transform the consumer market out there so there is more variety out there, we don't get this loss of continuity.”

“There will be lost horticulture lines and breeding programs - we put a lot of money in and it sinks in a year... this means less diversity in the long run, and less nutrition for consumers”

“Having crops in non-widestream areas will pull a wider ethnicity into the market...there are also consumers who want a new experience, and want to learn how to use a new product before they buy”

02.2 Results

System-level recommendations

Workshop learnings and recommendations

This page explores the major challenges identified and explored throughout the workshop activities. The primary purpose of this project was to identify major challenges and opportunities that require transformational change in the tropical and subtropical industries. While this purpose has been achieved to an extent, upon reflection on the workshop and project outcomes, the project team has a number of learnings that could support any further projects exploring industry transformational R&D needs. Areas for improvement include:

1 Identify challenges and opportunities through desktop research, and use interviews and workshops to collaboratively prioritise and build upon these findings.

There is extensive literature currently available on the major challenges facing individual crop types, and horticulture and agriculture in general. Future iterations of this project should involve more extensive desktop research on these topics, especially how these challenges will play out in the future (e.g. how will climate change impact horticulture in 10 years?). This information could be then used throughout the engagement process to prompt the stakeholders to look beyond Horizon 1.

2 Once the target challenges/ opportunities are identified, use the workshop to explore cutting-edge innovation and systemic changes that can support transformational R&D.

While exploring challenges and opportunities in the workshop setting was useful, there was a limit to the progress and innovative thinking participants could achieve. Transformational R&D will ultimately be identified and developed through systemic structures that provide an opportunity for explorative research that looks beyond Horizon 1 and 2 technologies.

Future transformational workshops should therefore have a stronger focus on those structures and collaborations that could support this transformational R&D. Thorough desktop research into innovative R&D structures could support workshop activities.

3 Invite a diverse group of stakeholders to ensure workshop outputs reflect industry needs, not just researcher needs.

Although a number of industry representatives were present at the workshop, future iterations should ensure that a range of industry stakeholders are present. Interviewing individuals of peak bodies provides an opportunity to gain buy-in not only from representative bodies, but also provides an opportunity to access major growers involved in these organisations to attend workshops. This can provide growers with an opportunity to express the transformational R&D that would most benefit them and the sustainability of their businesses, as well as challenges they have had accessing existing R&D structures. Future engagement efforts could therefore utilise peak body grower networks to engage stakeholders, and consider online engagement to allow a diverse group of stakeholders to attend.

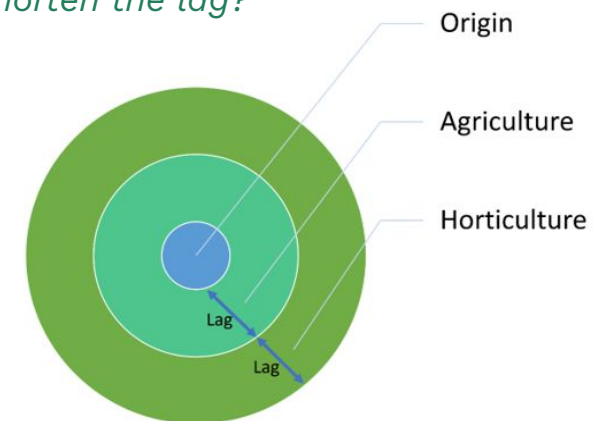
Overarching system-level recommendations

Through the final session of the workshop, a series of systemic changes were identified that would be required to 'normalise' the process of identifying transformational opportunities, and identifying the support and structures required to act upon them. Horticulture can rapidly advance by better scanning for, tailoring and integrating innovations from other sectors. The challenge is, how to do this quickly and shorten the lag time of identifying and adopting these innovations. Opportunities to systematically address these challenges are explored below. Further industry engagement and work is required to understand the feasibility and possible pathways for realising these recommendations.

1. Create probing systems to explore innovations in other sectors.

As explored in the workshop, horticulture rarely sits at the bleeding edge of scientific, technological, and product development cycles. Currently this poses a challenge for the sector, as it is often a laggard in technology adoption. However, technological and scientific developments in analogous industries present an opportunity to translate existing cutting edge research into the horticulture sector (e.g. defence, aeronautics, space, mining, automotive, biomedicine and human health) and allow challenges to be solved much faster than they currently are. Applying these learnings and enabling technologies to the challenges of horticulture, will bring innovations to bear much faster than is currently occurring. However, without a degree of coordination to ensure developments in analogous industries are understood and their applicability assessed, the industry is potentially missing out on the adoption of solutions that could transform the industry. Therefore, the industry requires a systemic and co-ordinated approach that can be dedicated to assessing innovations in analogous industries.

Innovation adoption into agriculture and horticulture industries: How do we shorten the lag?



If horticulture wishes to capture and spread innovations more rapidly, knowledge of those developments well before they would otherwise arrive in horticulture is required. Analytical probing systems should involve quantitative analysis of patents and trends in horticulture and in analogous sectors, to identify new technologies that could rapidly be applied to solving horticultural challenges. Paired with deep qualitative research, this approach would help to find and tailor technologies, and ensure that their path to adoption is effective.

Horticulture often witnesses the emergence, adoption and uptake of new developments after other areas of agriculture. This makes it quite possible to follow disruptions that emerge and then diffuse across sectors. This also provides an opportunity for funders, businesses, and peak bodies to play catch up with other sectors where a systematic analytical framework can be established. Seeing the disruptions emerge as early as possible provides the chance to focus attention and resourcing at these areas of investment. While disruptive technologies still impact the industry, choosing where to focus the transformational R&D dollar is enabled by an evidence-based assessment of disruptions in other sectors.

Overarching system-level recommendations

2. Design unique collaborative structures to encourage transformational R&D.

By necessity, DARPA lies at the bleeding edge where an evidence base doesn't exist that can be used to make judgements about the veracity and viability of potentially disruptive developments. However if Hort is seeking to shift the dial from business as usual to Leading edge, even if much of the portfolio it supports ranges between business as usual and leading edge, then an analytical function would assist judgements.

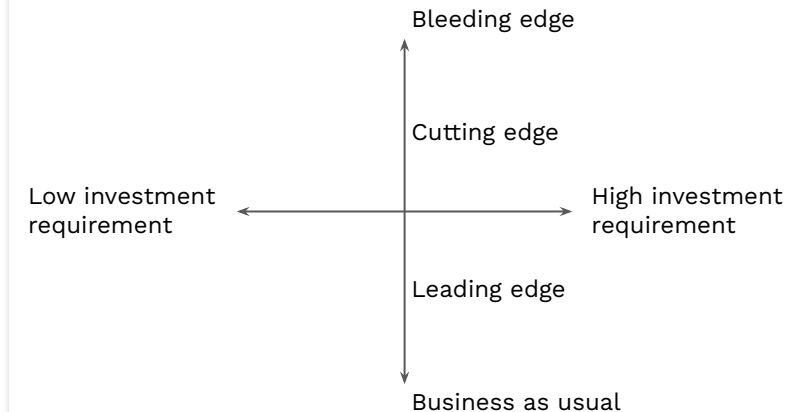
Models such as DARPA can be utilised to inspire similar structures in horticulture. DARPA utilises temporary teams brought together for a specific purpose/problem, and does not require short term returns on investments. This allows research and prototyping that is truly explorative, allowing room for experimentation and error. From the DARPA model, there have been numerous major technological developments, from the Internet to the Boston Dynamics Robot.

Learning from DARPA's multidisciplinary, temporary teams, their longer funding cycles, and their independence (which affords them an ability to take on the risks of transformational R&D), will provide insights into a new model for effecting transformational change in Australia's horticulture sector.

While it is acknowledged that horticulture does not have the risk appetite nor the funding to support this exact model, a 'DARPA-like' or 'DARPA-light' approach could be utilised that draws across industry funds, and brings together multi-disciplinary and sectoral teams to create DARPA-like research teams for horticulture. These teams could bring together a diversity of thought and path to market to ensure that solutions developed create the transformational value that is required.

Some disruptive developments do not actually require substantial investment, they may be simply a minor change in on-farm practices to deal with fungal or insect infestations. Others would require substantial investment which will also have an impact on adoptability of solutions if they were to emerge. These distinctions have structural implications for a funder. There may be some structural separation between the bleeding edge and business as usual units within the organisation their personnel, SOPs, investment criteria, scale and risk appetite will differ.

Disruptive versus investment required



Overarching system-level recommendations

3. Set specific tropical and subtropical horticulture targets.

While there are targets and focus areas in crop Strategic Investment Plans, and an overarching goal of increasing the horticulture sector's value to \$20 billion by 2030, there is a need to set more specific goals at a subtropical and tropical horticulture level to support cross-industry collaboration. This cross-industry goal setting could provide a platform to knowledge share and pool resources to tackle challenges that impact multiple crops.

“The whole of R&D is so heavily projectized, which is what industry says they want, which is reactionary...and we are losing good researchers because of it.... We need to start investing in people, can we invest together in people for certain strategic goals to be achieved, otherwise it's hard to train and retain them.”

“It also doesn't need to be farmer led all the time, research doesn't need to be full industry endorsed, because this assumes farmers know all the problems...Farmer led research is good, but there are also often things in the system that scientists know.”

“We need to be collaboratively setting horizon goals, not just a general goal to grow by \$X amount, we need to have goals like “defeat this specific challenge by 2030...”. Horticulture is not as well linked as other industries in this way, and we need to change that.”

“Maybe one idea blows it out of water, transforms sector, and then it's worth all the investment and all the potential “failures”...The concept of return on investment is critical, and organisations like DARPA get the money and they don't have to have the return on investment when they make a partnership, which isn't an option for Horticulture...So we need something that is recognisable as transformational, that also has a recognised level of failing and very slow path until you get impact or ROI.”



03. Appendices

03.1

Appendix A: Workshop Materials

Workshop Participants

The lists below identify the stakeholders who participated in the workshop.

| Name

| Position

TGD Facilitators

Dr David Ireland	Lead Facilitator, TGD Managing Director
Chloe Sterland	Support Facilitator, TGD Senior Designer
Nicole Gemlitski	Support Facilitator, TGD Designer

Project team / Internals

Prof Neena Mitter	Project leader, Director Centre for Horticultural Science, QAAFI
Prof Damian Hine	Professorial Research Fellow, QAAFI
A/Prof Femi Akinsanmi	Principal Research Fellow, Centre for Horticultural Science, QAAFI

Horticulture Innovation Australia

Adrian Hunt	R&D Manager, HIA
Ben Callaghan	R&D Manager, HIA

Industry / Industry Association

John Tyas	CEO Avocados Australia
Rosie Godwin	R&D Manager, Banana Growers Council
Ben Martin	Chairman, Australian Mangoes Industry Association
Kathy La Macchia	General Manager, Grains & Legumes Nutrition Council

| Name

| Position

Researchers

Rob Eccles	Manager, Crop and Field Research Unit, UQ
Yasmina Sultanbawa	Professor, Centre for Nutrition and Food Sciences, QAAFI
Andre Drenth	Professor, Centre for Horticultural Science, QAAFI
Stephen Harper	Associate Professor, School of Agriculture and Food Sciences, UQ
Lynn Hoffman	Senior Lecturer, School of Agriculture and Food Sciences, UQ
Mobashwer Alam	Research Fellow, Centre for Horticultural Science, QAAFI
Tim O'Hare	Associate Professor, Centre for Nutrition and Food Sciences, QAAFI
Chris Lehnert	Senior Lecturer, School of Electrical Engineering and Robotics, QUT

Government

Lynne Turner	General Manager, Horticulture and Forestry Science, QLD Department of Agriculture and Fisheries (QDAF)
Vicki Lane	Director, Horticulture and Forestry Science, QDAF
Ian Layden	Director Vegetables, Systems and Supply Chains, QDAF
Gary Hopewell	Acting Director, Subtropical fruit and genetic improvement, QDAF
Dario Stefanelli	Senior Scientist, WA Department Primary Industries and Regional Development

The biggest challenges & opportunities

| Activity Purpose

Following presentations exploring key challenges and opportunities (identified through interviews and surveys) the purpose of this activity was for the participants to collaborate and collectively identify the biggest challenges and opportunities facing the sector that they would like to explore throughout the workshop.

| Activity Overview

The participants were divided into diverse groups of five people, from industry to research, and government. They were asked to identify one or more major challenges/ opportunities facing the industry in 10 years. At the end of this activity participants shared their activity worksheets, and following these presentations, participants were invited to select the challenge/ opportunity they were most interested in exploring throughout the workshop. From these preferences, groups were formed that remained throughout the workshop.

Each group was given an A3 worksheet with four guiding questions. The four questions were:

1. **Who** has this or who will have it?
2. **What** impact is / will this challenge have?
3. **If this is solved** how will it transform the sector?
4. **How** are they trying to solve it now / how will they solve it in the future?

Activity One |

What are the biggest challenges facing Australian Horticulture?

In your groups, identify additional problems to solve / opportunities to realise

Name the big challenge or opportunity:

Who has this or who will have it? 	What impact is / will this challenge have over the next 1, 5, and 10 years? 
If this is solved, how will it transform the sector? 	How are stakeholders trying to solve it now? How will they solve it in the future? 

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The biggest challenges & opportunities worksheets

The worksheets below were completed by participants, and were the primary outputs from this activity.

Activity One |
What are the biggest challenges facing Australian Horticulture?

Name the big challenge or opportunity: CROP PROTECTION - SUSTAINABLE

Who has this or who will have it?
All producers
Farm workers
Environment
Consumers
Public Health
Chemical Companies

What impact is / will this challenge have over the next 1, 5, and 10 years?
↓ Quality into market
↑ Costs of production
labour
↑ Food waste
loss of export opportunities

If this is solved, how will it transform the sector?
① Improved safety to people & environment.
② Better social licence.
③ Better varieties
④ Better food & nutrition security

How are stakeholders trying to solve it now? How will they solve it in the future?
① Improve efficiency of Agvet Chem regulation
② New safer options eg biologics
③ Improved application
④ Resistant varieties
⑤ IPM adoption

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Activity One |
What are the biggest challenges facing Australian Horticulture?

Name the big challenge or opportunity: Location - distance to markets

Who has this or who will have it?
rural/region producers.
very badly exporters

What impact is / will this challenge have over the next 1, 5, and 10 years?
- increasingly a problem
- push as input costs rise
- inc. # disruptions

If this is solved, how will it transform the sector?
Prox. to Syd./Melb.
Can compete counter-seasonal
- make us globally competitive
- assured supply
- reduce prices?
- helps to address energy requirements

How are stakeholders trying to solve it now? How will they solve it in the future?
- expand transport network
- running road trains
- building infrastructure
- improve supply chain efficiencies/effectiveness.

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Activity One |
What are the biggest challenges facing Australian Horticulture?

Name the big challenge or opportunity: CHANGING CLIMATE

Who has this or who will have it?
unprepared industries
ENTIRE HORT INDUSTRY

What impact is / will this challenge have over the next 1, 5, and 10 years?
1- disruptions in supply chain
5- change in consumer preferences
10- nutritional deficiencies

If this is solved, how will it transform the sector?
- preparedness - accelerated tree breeding crops
- technologies for management systems
- selection for resilient crop

How are stakeholders trying to solve it now? How will they solve it in the future?
- predictive agriculture.
- protected cropping
- accelerated breeding
- processing / new product development
- consumer education.

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Activity One |
What are the biggest challenges facing Australian Horticulture?

Name the big challenge or opportunity: INPUTS - FERTILIZER, FUEL, ENERGY.

Who has this or who will have it?
All producers
Consumers
Supply Chain
Resellers
Public

What impact is / will this challenge have over the next 1, 5, and 10 years?
↓ Profitability
↑ Cost of production
Social licence to operate
Industry viability
Energy innovation

If this is solved, how will it transform the sector?
↑ Viability & sustainability
- ↓ C emissions
- less reliance on overseas supply (fertilizers)
- Maintain consumer acceptance

How are stakeholders trying to solve it now? How will they solve it in the future?
① Investigating automation
- lobbying / access to international workers.

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Activity One |
What are the biggest challenges facing Australian Horticulture?

Name the big challenge or opportunity: LABOUR

Who has this or who will have it?
All producers
Supply Chain
Consumers - part. low income
manufacturers

What impact is / will this challenge have over the next 1, 5, and 10 years?
Profitability
Viability
short - poor quality fruit in market
- poor prices
- growers exiting industry
med-long - threat of imports
- food security sovereignty
- ↓ public health

If this is solved, how will it transform the sector?
Improved resilience
Better profitability

How are stakeholders trying to solve it now? How will they solve it in the future?
① Investigating automation
- lobbying / access to international workers.

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Activity One |
What are the biggest challenges facing Australian Horticulture?

Name the big challenge or opportunity: consumer awareness + education

Who has this or who will have it?
growers → market awareness
consumers → lack awareness
how to use frv
retailers

What impact is / will this challenge have over the next 1, 5, and 10 years?
1 loss of continuity
5 lost hort roles
10 less diversity, options

If this is solved, how will it transform the sector?
- more choice, variety
- less waste
- broader nutrition options

How are stakeholders trying to solve it now? How will they solve it in the future?
- filter down using social media, celebrity cooking + similar TV

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The biggest challenges & opportunities worksheets

During the discussion, the group reached a consensus that the challenge “global competitiveness” at hand was an overarching one that encompassed the other various challenges. They acknowledged that addressing and solving these challenges would ultimately contribute towards achieving this main objective. This means the group recognized that the issues at hand were interconnected and that a comprehensive approach was necessary to realise this big opportunity.

Activity One |

What are the biggest challenges facing Australian Horticulture?

In your groups, identify additional problems to solve / opportunities to realise

Name the big challenge or opportunity: *yield + quality → production efficiency “Global Competitiveness”*

Who has this or who will have it?  <i>All hort sectors</i>	What impact is / will this challenge have over the next 1, 5, and 10 years?  <i>new export opportunities</i> <i>Sustainable domestic production</i> <i>IMPORT → competition with.</i>
If this is solved, how will it transform the sector?  <i>→ Supply chain improvements</i> <i>→ Sector will grow greater employment.</i> <i>→ Value</i> <i>→ Reduction synthetic fertiliser</i>	How are stakeholders trying to solve it now? How will they solve it in the future?  <i>→ Automation.</i> <i>→ Value addition, beyond fresh produce. (FUTURE + CURRENT.)</i>

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The biggest challenges & Opportunities

A total of seven challenges and opportunities were identified among the four groups. The identified challenges and opportunities provided a basis for the participants to expand upon in the next activities. The key points are outlined below.

1 Market consumer awareness

- **In 10 years...** “There will be lost horticulture lines and breeding programs
- we put a lot of money in and it sinks in a year... this means less diversity in the long run, and less nutrition for consumers”
- **If this is solved...** “We want to transform the consumer market out there so there is more variety out there, we don't get this loss of continuity.”
- **How will this be solved...** “Current social media and these popular shows are very important to have a feed down system in the market rather than a feeding up, and this will play a critical role in bringing new varieties and innovations to market.”

2 Changing Climate

- **In 10 years...** “This challenge will influence the variety of foods and crops that we will have available, especially if the conditions mean it is much more difficult to grow. Some crops could be extinct in the food supply.”
- **If this is solved...** “We will have more resilient crops...and this involves ensuring Industry preparedness so you can introduce new varieties, developing interventions including technology to manage farm systems”
- **How will this be solved...** “Protected cropping solutions and accelerated breeding (especially for tree crops) will be major solutions... we also need to change the way we process (new product development).”

3 Transport

- **In 10 years...** “Increased growth of the industry will be a problem, even though it will be a critical response to more demand and a greater population... this will also mean input costs rise and transport costs get more expensive.”
- **If this is solved...** “Making ourselves globally competitive and ensuring supply and food security... reducing costs of production...helping with energy issues and the credentials of industry in relation to emissions.”
- **How will this be solved...** “Evolutionary approaches: expanding and allowing road trains to put in more exports... it also involves looking at supply chains themselves and improving the shelflife of those supply chains.”

Note: Numbers and box sizes are not ranked.

The biggest challenges & Opportunities

A total of seven challenges and opportunities were identified among the four groups. The identified challenges and opportunities provided the basis of what the participants have expanded on in the next activities. The key points are outlined below.

Labour

- **In 10 years...** “There will be decreases in profitability and viability, which creates poor quality fruit in the market, reduces food security, and there’s also a cost increase and general public health ramifications.”
- **If this is solved...** “Improved resilience and profitability”
- **How will this be solved...** “Stakeholders are looking at it now and investigating and looking into automation, lobbying and sources internationally”

Inputs fertiliser, fuels and energy

- **In 10 years...** “there will be major decreases in industry profitability due to our reliance on these inputs.”
- **If this is solved...** “The industry will have Increased liability and sustainability through decreased carbon emissions...we will also reduce reliance of overseas supplies (especially regarding fertilisers).”
- **How will this be solved...** “We need to look into areas around energy innovation.”

Sustainable crop production

- **In 10 years...** “There would be reduced quality in the market, increases in food waste and potential loss of export opportunities.”
- **If this is solved...** “There will be improved safety in environment, and better food and security.”
- **How will this be solved...** “Improvements in efficiencies, as well as softer options for crop production, including the use of biologicals.”

Global Competitiveness

- **In 10 years...** “This opportunity could impact the whole tropical and subtropical industry, creating new export opportunities, and sustainable domestic opportunities.”
- **If this is solved...** “The sector will be able to grow, and there will be greater employment and profitability”
- **How will this be solved...** “Traditional methods, as well as adopting technology that is available. This can reduce costs, and in the future growers can continue to adopt solutions to these challenges.”

Note: Numbers and box sizes are not ranked.

How do we address these challenges?

| Activity Purpose

The purpose of this activity was to begin to get participants to consider existing technology available that could be utilised to overcome challenges/ realise opportunities (within subtropical and tropical industries and analogous industries), and what technology would be required that was currently not available. This activity was also critical in interrogating if a technology solution would be developed and brought to market without industry R&D investment (i.e. was there a market failure).

| Activity Overview

Based on the challenges selected in the previous activity, participants explored the following questions:

1. What is the challenge / opportunity?
2. Who is / will experience it?
3. Does the technology exist (alone or in combination) in a parallel industry that we could use to solve this / realise this?
4. If no technology exists, what R&D do we need to invest in to solve/ realise this?
5. Who has the capability to undertake this R&D?
6. Is this challenge already being solved by someone? If yes, who and how?

Activity Two |

How do we address these challenges?

Name the challenge or opportunity you are solving:

Who is / will experience it? 	If no technology exists, what R&D do we need to invest in to solve/ realise this? 
Does the technology exist (alone or in combination) in a parallel industry that we could use to solve this / realise this (don't worry about funds for now!)? 	Who has the capability to undertake this R&D? 
Is this challenge already being solved by someone? If yes, who? 	

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How do we address these challenges worksheets

The worksheets below were completed by participants, and were the primary outputs from this activity.

Activity Two |

How do we address these challenges?

Name the challenge or opportunity you are solving: New Paradigm for CROP PROTECTION

Who is / will experience it?	If no technology exists, what R&D do we need to invest in to solve/ realise this?
Ad hort. → Planetary benefits → Society Plant human health Enviro	softer chemistry New knowledge Image analysis/detection tool Integrated precision tool
Does the technology exist (alone or in combination) in a parallel industry that we could use to solve this / realise this (don't worry about funds for now)?	Who has the capability to undertake this R&D?
Yes Private industries R&D stakeholders → Output	Biopesticide Smart identification (detection tools) Rapidism UR/ DAF Outback robotics (agriculture)
Is this challenge already being solved by someone? If yes, who?	
DAF → New initiative on Consortium for Reduction in Synthetic Chemicals in Ag food systems (CRS CAF) Private bio-protection companies	

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Activity Two |

How do we address these challenges?

Name the challenge or opportunity you are solving: LOGISTICS | SUPPLY CHAIN

Who is / will experience it?	If no technology exists, what R&D do we need to invest in to solve/ realise this?
Producers Consumers Under Supply Chain	Technology Exists Need Invest Optimised market Sustainable Cold Supply CHAIN
Does the technology exist (alone or in combination) in a parallel industry that we could use to solve this / realise this (don't worry about funds for now)?	Who has the capability to undertake this R&D?
For Cold CHAIN - Pharma Waste Usage eg Biofuels - Nutritional Blockchain - Ecoscore	Big Producers - Pharma Equipment Suppliers
Is this challenge already being solved by someone? If yes, who?	
Not follow USA/EU example we geographically differ.	

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Activity Two |

How do we address these challenges?

Name the challenge or opportunity you are solving: Changing Climate

Who is / will experience it?	If no technology exists, what R&D do we need to invest in to solve/ realise this?
entire sector Growers supply chain consumers	pick candidate crops - infrastructure breed crops for protective cropping environments to produce any crops anywhere; any climate Multi-disciplinary teams - DAF/Industry energy - technology solutions partners
Does the technology exist (alone or in combination) in a parallel industry that we could use to solve this / realise this (don't worry about funds for now)?	Who has the capability to undertake this R&D?
predictive technology → becoming available protective cropping technology breeding for resilient crops genomics & genetics	DAF/Industry partners
Is this challenge already being solved by someone? If yes, who?	
New IP Tropical/Subshop. crops cattle industry → emission Netherlands/Asia	

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Activity Two |

How do we address these challenges?

Name the challenge or opportunity you are solving: LABOUR

Who is / will experience it?	If no technology exists, what R&D do we need to invest in to solve/ realise this?
All producer Consumers Supply chain Resilient Robotic	Taking appeal to horticulture/ag/ regional areas. ↓ cost
Does the technology exist (alone or in combination) in a parallel industry that we could use to solve this / realise this (don't worry about funds for now)?	Who has the capability to undertake this R&D?
Some technology exists to existing technology (efficient, stronger) all energy source H₂, electric, solar sell right systems, genetics (CRISPR) midstream, e DNA research	Uni's, Govt RO, Private industry Classes RO, Elen Robotics Adapt technology to HORT Adapt HORT to technology.
Is this challenge already being solved by someone? If yes, who?	
Focus on urban delivery Foundational R&D Grains → nutrition Microbiomes/ endophytes Regional Sustainable energy prodn hub Energy storage tech.	

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Activity Two |

How do we address these challenges?

Name the challenge or opportunity you are solving: LABOUR

Who is / will experience it?	If no technology exists, what R&D do we need to invest in to solve/ realise this?
production + supply chain	Need technical skills Improved automation. Smart picking robot GAPE Climbing application in HORT
Does the technology exist (alone or in combination) in a parallel industry that we could use to solve this / realise this (don't worry about funds for now)?	Who has the capability to undertake this R&D?
Automation Robotics Adapt technology to HORT Adapt HORT to technology.	Breeding Canopy management Robots for HORT - Uni SYD
Is this challenge already being solved by someone? If yes, who?	
Manufacturing industry Packing shed Military Fruit identification in complex canopies. NEED Technical Support - Cluster effect.	

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Activity Two |

How do we address these challenges?

Name the challenge or opportunity you are solving: Consumer market for non-mainstream F&V. (Durian/Heirloom varieties)

Who is / will experience it?	If no technology exists, what R&D do we need to invest in to solve/ realise this?
Ethnicity under-represented The consumer who wants new experience Farmers who adopt new commodity.	To increase scale of prototypes. Need the prototype & access to germplasm. Or, CRISPRs transformation (backdoor in Aust)
Does the technology exist (alone or in combination) in a parallel industry that we could use to solve this / realise this (don't worry about funds for now)?	Who has the capability to undertake this R&D?
Some things - Varieties already exist For others - eg. inter-disease developed (eg. purple varieties of sweetcorn)	DAF Industry/seed companies (ages/melons) International collaborations to access germplasm (true species)
Is this challenge already being solved by someone? If yes, who?	
Awareness of some new products via reality cooking shows. (MKR) What is being observed overseas, that could be applied here. eg. ACIAR, Seed companies. Commonwealth/industry/government Consumer changes over time Preservation of diversity/germplasm Old product no longer (revaluing)	

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How do we address these challenges?

As part of the seven challenges and opportunities identified, participants prioritised six challenges, all of which overlap with crop protection, climate change, and energy use.

1 Market Viability

- “Having crops in non-widestream areas will pull a wider ethnicity into the market...there are also consumers who want a new experience, and want to learn how to use a new product before they buy...old products are not growing because of Australian population ethnicity changes. We need to continuously be on top of this to make sure what consumers want is delivered.”
- “Convenience is key in new developments...people don't have intellectual space to adapt and do something different and they'll go for the tastiest most convenient product.”

2 Changing Climate

- “Easy crops like tomatoes and cucumbers have been solved... but tree and long term crops are harder to solve... we need to breed crops for protective climates, so we can supply crops independent of climate.”
- “We need good infrastructure that is suitable for Australia, not necessarily from Europe.”
- “A major opportunity for tropical and subtropical crops is protected cropping... we've never invested in that area before but we need to think what our competitive advantage is in protected cropping... we should only adapt crops if we know the crop, we know how it works in the orchard. Only when we have that, we have the ability to adapt crop for new, protected environments.”

3 Distance to market

- “A lot of tech exists, it's more of an investment issue... the top 3-4 big producers can play a major role in solution investing and solution adoption.”
- “We always think we can mimic the EU and US, but the distance here is completely different... we need to find our own solutions”
- “Uber and Amazon are good examples of complete disruption in the supply chain...we need to look at how that's happened.”

Note: Numbers are not ranked.

How do we address these challenges?

As part of the seven challenges and opportunities identified, participants prioritised six challenges, all of which overlap with crop protection, climate change, and energy use.

Labour

- “We are doing things now regarding fruit identification in complex canopies with smart robots, and this also includes canopy management projects with in HIA at the moment.”
- “With labour and robotics, the technical role in big businesses is always forgotten... if there’s a medium size, can you have a graduate to run the robotics? And this could be a major barrier, because there’s a lack of technically skilled labour in Agriculture...robots will always need humans in some way.”
- “It’s important to provide information to growers that they can easily interpret.”
- “We can think about robotics not only during harvest, but also supporting other labour needs (in sheds etc.).”

Energy

- “There are major opportunities for improved battery efficiency and hydrogen batteries... there are also regional sustainable energy hubs popping up that could be utilised.”
- “In terms of solution that doesn’t exist... it might exist in other industries, but does not have application horticulture or regional areas yet...there’s massive cost of implementation or utilisation in these regional areas.”

Crop Protection

- “We recognise that many tech solutions are out there, but some are not good, and get into market even though they aren’t effective.”
- “We need to measure the pipeline in terms of readiness from 1-9...We need investment and this means a systemic approach and more coordination... RDCs are interested in ready for market products, and this needs to be demonstrated to them...the private sector is usually not going to invest in this.”
- “It’s a young industry...a lot of the small players running around, it’s not an ecosystem yet.”

Note: Numbers are not ranked.

Supporting R&D development

| Activity Purpose

The purpose of this activity was to encourage participants to think about transformational R&D opportunities that can be used to address the challenges and opportunities identified in previous activities.

To get participants thinking in a more systematic and strategic way, activity 3 & 4 worksheets were combined and completed straight after each other. These activities have therefore been combined in this document.

| Activity Overview

Based on the challenges selected in the previous activity, participants explored the following questions:

1. What transformational R&D are you developing?
2. How does this technology get tested and proven in a relevant industry environment?
3. What enabling technologies are required for the transformational R&D to be turned into a usable product / service?
4. What funding models are appropriate to do this?

Activity Three |

How do we support the development of this transformational R&D?

What needs to happen to facilitate this transformational R&D?

What challenge/ opportunity are you solving?

What transformational R&D are you developing?



How does this technology get tested and proven in a relevant industry environment?



What enabling technologies are required for the transformational R&D to be turned into a usable product / service?



What funding models are appropriate to do this?



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Supporting R&D development worksheets

The worksheets below were completed by participants, and were the primary outputs from this activity. As the activities were combined in the workshop, the purpose and outputs of activity 4 are explored on the following page.

Activity Three | How do we support the development of this transformational R&D?

What needs to happen to facilitate this transformational R&D?

What challenge/opportunity are you solving? **Increasing challenges in use of Chemicals.**

What transformational R&D are you developing? **Integrated pipeline for biological approach to managing Pests**

How does this technology get tested and proven in a relevant industry environment? **AD/N29**

What enabling technologies are required for the transformational R&D to be turned into a usable product/service? **AD/N29**

What funding models are appropriate to do this? **3P Partnership (Long-term)**

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Activity Three | How do we support the development of this transformational R&D?

What needs to happen to facilitate this transformational R&D?

What challenge/opportunity are you solving? **Logistics/Supply chain**

What transformational R&D are you developing? **Innovate to minimise miles and waste on the supply chain**

How does this technology get tested and proven in a relevant industry environment? **Loss of nutrient quality**

What enabling technologies are required for the transformational R&D to be turned into a usable product/service? **Env. Sub. Governance**

What funding models are appropriate to do this? **ESG Investors**

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Activity Three | How do we support the development of this transformational R&D?

What needs to happen to facilitate this transformational R&D?

What challenge/opportunity are you solving? **Climate Resilient Production Systems (of climate change)**

What transformational R&D are you developing? **New climate adapted varieties (in Protected cropping & in Field)**

How does this technology get tested and proven in a relevant industry environment? **Whole of horticulture**

What enabling technologies are required for the transformational R&D to be turned into a usable product/service? **Gene editing**

What funding models are appropriate to do this? **All levels of involvement**

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Activity Three | How do we support the development of this transformational R&D?

What needs to happen to facilitate this transformational R&D?

What challenge/opportunity are you solving? **Renewable, cost-effective, sustainable energy supply (electric)**

What transformational R&D are you developing? **Renewable energy supply**

How does this technology get tested and proven in a relevant industry environment? **Smart farms**

What enabling technologies are required for the transformational R&D to be turned into a usable product/service? **Storage tech (Energy)**

What funding models are appropriate to do this? **Fed/State Govt**

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Activity Three | How do we support the development of this transformational R&D?

What needs to happen to facilitate this transformational R&D?

What challenge/opportunity are you solving? **Labour**

What transformational R&D are you developing? **Robot adaptable to many crops**

How does this technology get tested and proven in a relevant industry environment? **Robot adaptable to many crops**

What enabling technologies are required for the transformational R&D to be turned into a usable product/service? **Robot adaptable to many crops**

What funding models are appropriate to do this? **Challenge model**

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Activity Three | How do we support the development of this transformational R&D?

What needs to happen to facilitate this transformational R&D?

What challenge/opportunity are you solving? **Viability of non-mainstream F&V**

What transformational R&D are you developing? **Transit dev. (new or existing adapted to an export market)**

How does this technology get tested and proven in a relevant industry environment? **Timing of product availability**

What enabling technologies are required for the transformational R&D to be turned into a usable product/service? **Transit dev. (new or existing adapted to an export market)**

What funding models are appropriate to do this? **Multi-step from**

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Supporting R&D development

| Activity Purpose

After identifying transformational R&D solutions in activity 3, participants investigated methods of adoption and considerations in relation to other technologies, models, and policy changes.

| Activity Overview

Based on the transformational R&D solutions identified in the previous activity, participants explored the following questions towards adoption:

1. What is the pathway to end user adoption?
2. How do we nudge the behaviours of the end users in the direction of adoption?
3. What else in the system needs to change to support adoption? E.g. policy? Other technology solutions. New business models?

Activity Four |

How do we get these transformational solutions adopted?

What challenge/ opportunity are you solving?

Name the R&D area:

What is the pathway to end-user adoption?



How do we nudge the behaviors of the end users in the direction of adoption?



What else in the system needs to change to support adoption? (e.g. policy, other technology solutions, new business models)



Session 4

Supporting R&D development
worksheets

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Activity Four |

How do we get these transformational solutions adopted?

What challenge/ opportunity are you solving?
Name the R&D area: CRDP PROTECTION

What is the pathway to end-user adoption?
→ Co-Design
→ On-farm demonstration cum development
→ Education - social acceptances
System
R&D
→ CO-DESIGN
→ PRODUCE
→ CONSUMERS
→ Value proposition
→ Value proposition

How do we nudge the behaviors of the end users in the direction of adoption?
→ Education - systems approach
→ POLICY SUPPORT CHALLENGE
→ ATTENDANCE CAMPAIGN
→ CONSUMER BEHAVIOR - to complete projection trends
→ Value proposition

What else in the system needs to change to support adoption? (e.g. policy, other technology solutions, new business models)
→ POLICY
→ SUSTAINABILITY VALUE (e.g. ECO SCORE)

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Activity Four |

How do we get these transformational solutions adopted?

What challenge/ opportunity are you solving?
Name the R&D area: LOGISTICS / SUPPLY CHAINS
AUSTRALIAN SPECIFIC NOT FOLLOWING INTERNATIONAL

What is the pathway to end-user adoption?
→ 1. QUALITY - FLAVOR
→ 2. SUSTAINABILITY
→ 3. PROVENANCE
→ 4. HUMANITARIAN
→ 5. TRANSPARENT + VISIBLE - TO MAKE INFORMED CHOICES NOWHERE EMISSIONS

How do we nudge the behaviors of the end users in the direction of adoption?
→ REGULATION → TRANSPARENCY
→ DIETARY GUIDELINE
→ CONVENIENCE WHOLE FOODS
→ TARGETED EDUCATION + AWARENESS - ESP. TRAVEL + DISTANCE
→ MULTITASKINGLY INCREASE HEALTH VALUE
→ TASTE, NUTRITION ALL AT ONCE
→ EXCITING COMBINATIONS INDUSTRY CONCENTRATION
→ EMPEROR - NEGOTIATED KILLS THIS
→ LOOK AT 1 INDUSTRY THAT ARE SUCCEEDING WITH A LARGE NUMBER OF SMALL PLAYERS - BUT INDUSTRY CONCENTRATION KILLS THIS
→ HOW DO WE DIFFUSE FARM SYSTEMS PARTIALS - BUSINESSES THAT ARE NOT EASY TO DIFFUSE

What else in the system needs to change to support adoption? (e.g. policy, other technology solutions, new business models)
→ COUNTER LOBBYING POWER OF ULTRA - PROCESSORS
→ ICONIC LEADERS E.G. CHEFS TO LEAD CULINARY INNOVATION
→ STAKE SYSTEM FOR SUSTAINABILITY - LCA BASED

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Activity Four |

How do we get these transformational solutions adopted?

What challenge/ opportunity are you solving?
Name the R&D area: Climate Resilient Production Systems
Fossil fuel free - zero-carbon economy - closed loop - profitable protected cropping system

What is the pathway to end-user adoption?
→ Demand of commercial viability
→ PC producers champion the transition
→ "Seeing is believing"
→ Special purpose funding vehicle to determine feasibility
→ Workforce + skill + education
→ Demonstration → innovation corridor

How do we nudge the behaviors of the end users in the direction of adoption?
→ ESG obligations
→ Consumer demand + expectations
→ PC-ZNE - TICK
→ "Climate friendly" fear, Goodbye our good-for-me planet.
→ (cf. price + convenience)
→ Transparency in the supply chain
→ Regional planning + policy consistency for protected cropping proponents
→ Infrastructure - water, energy

What else in the system needs to change to support adoption? (e.g. policy, other technology solutions, new business models)
→ Recognition of lower production risks with contracts along the supply chain + inputs
→ Reasonable planning + policy consistency for protected cropping proponents

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Activity Four |

How do we get these transformational solutions adopted?

What challenge/ opportunity are you solving?
Name the R&D area: Renewable, cost-effective, sustainable energy supply

What is the pathway to end-user adoption?
→ Proven technology - broad applicability
→ Demonstrate value proposition
→ Find industry champion strategy
→ Good business / adoption / industry strategy
→ Local market pull (consumers, Green stores/retailers, export markets where you're in 10 yrs time investments) + cost policy changes in current state availability + cost of current energy
→ Smooth transition approaches (product / supply chain / equipment / support) - business continuity affected by policy / compliance / ESG changes
→ Good news stories / announcements

How do we nudge the behaviors of the end users in the direction of adoption?
→ Provide support to transition
→ Independent, proven assessment of tech / potential
→ Use forecasting as driver, where you're in 10 yrs time investments
→ Cost policy changes in current state
→ Cited compliance requirements
→ Offer from niche market opportunities / advantage
→ Business continuity affected by policy / compliance / ESG changes
→ Good news stories / announcements

What else in the system needs to change to support adoption? (e.g. policy, other technology solutions, new business models)
→ Policy
→ Improve cost-effective tech
→ New business models
→ New production / process models
→ Infrastructure requirements (equipment / support)
→ Technical challenges
→ How do you transition (micro + macro level)
→ Community buy-in, potential co-ops
→ A change mindset
→ They need to come in red, blue and green
→ Market competition + supply options

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Activity Four |

How do we get these transformational solutions adopted?

What challenge/ opportunity are you solving?
Name the R&D area: LABOUR. AUTOMATION / ROBOTICS.

What is the pathway to end-user adoption?
→ Start with low hanging fruit
→ Pruning, weeding
→ Mowing, spraying
→ Harvesting
→ Phased introduction (labour → robots)
→ FOMO
→ Staff do trust
→ Robotics as a service

How do we nudge the behaviors of the end users in the direction of adoption?
→ Free trials
→ Outlining the benefits
→ Subscription system
→ Spin off technology [standard model] MIT
→ Entrepreneurship

What else in the system needs to change to support adoption? (e.g. policy, other technology solutions, new business models)
→ Safety standards
→ Risk management
→ Contractors
→ Safety standards
→ Risk management
→ Contractors

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Activity Four |

How do we get these transformational solutions adopted?

What challenge/ opportunity are you solving?
Name the R&D area: NON-MAINSTREAM (TRAD. FRUIT / NEW PRODUCTS / NOVEL CUS.)

What is the pathway to end-user adoption?
→ PROTECT DESP / MARKET RESEARCH (R&D)
→ DOES DOMESTIC MARKET NEED BREAKING OR IS THERE AN EXISTING MARKET (ETHNIC CH)
→ ENOUGH SEED / CV. READY TO GO
→ REALITY SHOWS / RELEASE TO RETAIL
→ CONSUMER

How do we nudge the behaviors of the end users in the direction of adoption?
→ Looking shows / social media
→ Hybrid feed-down
→ Courses new market
→ Engage target grower early
→ Grow small growers
→ DIRECT MARKETING - e.g. AMAZON
→ Good partner - e.g. Perfectus Fresh via Hello Fresh

What else in the system needs to change to support adoption? (e.g. policy, other technology solutions, new business models)
→ IP management may need to change (re who is the best grower for the product)
→ ↑ Supply chain expertise
→ Cultivation expertise for new crop + quality maintenance

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Supporting R&D development

The participants identified six transformational R&D solutions and adoption results (activities 3 and 4) that have some interconnectedness. Additionally, "changing climate" and "protected cropping" have a very strong interconnection, and have been combined below.

1 Market Viability

- "We need linkages between product development and market development, having those in parallel...this will help establish the early market insights, using tools such as simulations (test it with focus groups before putting in market)...we also need to engage target growers early in the development, not in the idea phase but a bit after it so they can see examples."
- "Ensuring cultivation expertise will be critical for adoption - you can have a great product but if you don't look after it properly, you can kill the product."
- "If we don't invest in this, you'll get a product from overseas and then they will be in control of the market...if we don't start to invest in stuff like this you'll lose a lot of good farmers...and we don't want to lose any more farmers that are really good."
- "Retail is also an important element of new products to market. If they don't want to put the effort in, it may struggle to succeed. The size of grower matters, the big ones have the relationship with the supermarket and if they have a range of products then they will have better pull."

2 Changing Climate/ Protected Cropping

- "We are exploring protected cropping systems that don't have an environmental footprint."
- "To nudge behaviours for adoption, we need to drive home measurable progress towards ESG (public holistic companies)...things like consumer facing "zero net emissions" tick show consumers that its a climate friendly product...Market segmentation is a key consideration in this."
- "The system needs transparency for people to see how well their produce travels, infrastructure opportunities to meet water and energy needs... and it needs to be communicated and recognised that a protected cropping environment has lower production risks."
- "We have to co-design with consumers, developers and scientists. If we just do this in a lab we may end up in the same boat as GMO, the worst social campaign ever developed...We also need a systems-wide approach to a education awareness campaign, including impact analysis and value adding, communicating what the value is to a grower even if it is more expensive."
- "There are many new big and small companies developing innovations, there are opportunities overseas to review and adopt some of these chemistries, and Integrated biological approaches to managing pests are coming from discovery to market...but without policy and investment, they will just stop doing it, that's the market failure."

Note: Numbers are not ranked.

Supporting R&D development

3 Distance to market

- “We need to not follow the US and EU because we are different...We do need a cross pollination of ideas from different industries, for example mining and pharmacy industries...we also need to look at different business models for the supply chain.”
- “We need ESG investors with transparent sustainability (for example, Philips lighting and the horticulture sector in the netherlands). Hort innovation should play a leading way to change the mindset of the industry too.”
- “We need to take a holistic approach, look at the whole supply chain, and ensure the quality of the measures to assess sustainability...These metrics are usually cherry picked. For example; if you are talking about sustainability then you can often focus on the packaging, even though the product itself may not be sustainable...this links in with education awareness around travel and distance”

4 Labour

- “We need robots that are adaptable to many crops, and test these solutions at different levels of complexities. There almost needs to be a “just do it and get started” attitude and then from that we can learn how to improve...Investment in robotics in tropical crops has been very little.”
- “We need to start with low hanging fruit - simple things, then harvesting later. We should also take a phased Introduction approach, from people to robots (you still need labour and they need to get used to the robots). We could also look at “robots as a service” models or subscription services to support adoption, and potentially free trials on some farms (if you demonstrate on a few, they all want it).”

5 Energy

- “To prove and test this technology we need prototypes, case studies, smart farms, feedback loops, economic assessments...and we need to make sure we are not looking only at the weaknesses, but also the unintended benefits.”
- “There are a range of enabling technologies needed, from storage technology (looking at energy and material spaces) to Generation technology, how are you generating a sustainable energy supply (we can look at algae for this).”
- “For end-users, we need proven technology that is scalable and can have broader applicability to the industry...Availability and cost of current energy as a driver and motive to change will be essential in communicating these solutions, as well as ensuring a smooth end user adoption, from supply chain, to equipment and physical resources.”

Note: Numbers are not ranked.

How does HIA support transformational development in R&D in an investment strategy?

| Activity Purpose

The purpose of this activity was to get the participants thinking about HIA and where they can fit in supporting the developments of transformational R&D in the challenges and opportunities explored above in mind.

| Activity Overview

In their groups, participants discussed how HIA can support transformational R&D in Tropical and Subtropical R&D as a whole using these prompting questions:

1. Can this be achieved with BAU?
2. What needs to be done differently to enable transformational R&D to be supported and adopted industry wide?
3. Who does HIA need to partner with to identify transformation opportunities and deliver on them?
4. How do we speed up the process of transformation?

The activity led to a plenary discussion rather than participants reading through their findings.

Activity Five |

How does HIA support transformational development in R&D in an investment strategy?

What needs to be done differently to enable transformational R&D to be supported and adopted industry wide?		
Can this be achieved within BAU activities? 	How/ who identifies the R&D challenge to be solved? 	How is performance of the investment assessed and managed? 
Describe the skill set and experience of the person managing the investments. 	Who does HIA need to partner with to identify transformational opportunities and deliver on them? 	How do we speed up the process of transformation? 

Final discussions

Based on the results of this activity, a constructive discussion emerged. The following are quotes from different people with varying backgrounds and perspectives.

“We need to be collaboratively setting horizon goals, not just a general goal to grow by \$X amount, we need to have goals like “defeat this specific challenge by 2030...”. Horticulture is not as well linked as other industries in this way, and we need to change that.”

“Maybe one idea blows it out of water, transforms sector, and then it’s worth all the investment and all the potential “failures”...The concept of return on investment is critical, and organisations like DARPA get the money and they don’t have to have the return on investment when they make a partnership, which isn’t an option for Horticulture...So we need something that is recognisable as transformational, that also has a recognised level of failing and very slow path until you get impact or ROI.”

“The whole of R&D is so heavily projectized, which is what industry says they want, which is reactionary...and we are losing good researchers because of it.... We need to start investing in people, can we invest together in people for certain strategic goals to be achieved, otherwise it’s hard to train and retain them.”

“It also doesn’t need to be farmer-led all the time, research doesn’t need to be full industry endorsed, because this assumes farmers know all the problems...Farmer-led research is good, but there are also often things in the system that scientists know.”

“Be more accepting of risk in research...the “this is my endpoint” constraints thinking...if you know the exact experiments happening, it wouldn’t be research.”



03.2

Appendix B: Interview and Survey Insights

Overarching Industry Challenges & Opportunities

The challenges and opportunities presented on this page highlight the main areas identified during the interviews and surveys that require transformational change across the different tropical and subtropical crops and regions.

1 Improve access to markets.

“We need to improve how we access and maintain access to international markets. Lack of consistent supply and quality kills long term export contracts.”

“Everyone knows fruits and veg are good. That’s not the problem. The problem is people not knowing how to use them.”

2 Adapting to changing environmental conditions and climate policy.

“Coping with the operational challenges accompanying deployment of zero emission technologies is challenging. It is hard to justify the operational expense when we see no significant increase in sales.”

3 Resilience against biosecurity threats and pest incursions.

“Without certain ag chemicals, there are major challenges, such as resistance in pest populations, MRL breaches, poor fruit quality.etc.”

“Climate change is introducing new threats. We need to make decisions about the future now, rather than respond to today.”

4 Maintaining profitable businesses despite increased costs of production.

“Without a clear R&D strategy in automation and scalability of indoor farming, the industry will not be able to achieve its environmental goals and is very likely to scramble.”

5 Improving supply of labour that meet business needs.

“There’s the potential to build business capacity if suitably experienced people can be sourced.”

“We cannot continue to be so reliant on imported workers. The nature of the work is changing, and so must our approach to labour.”

Overarching Industry R&D System Needs

The insights below from the [interviews and surveys](#) highlight the research required to support transformational thinking and change, as well as systemic issues that need to be addressed. Please see Appendix B for detailed insight pages.

1 Providing climate data to direct and support R&D adoption and acceleration

"R&D needs to look into what is the best way looking to grow each crop considering the weather and future in 2050."

"Data needs to be provided in a way that is consumable by growers."

2 Understanding consumer preferences to enhance solution uptake

"How do we better understand the diversity of current and future consumer preferences so we can nudge people in the right way to make the right choices."

3 Developing R&D solutions that respond holistically to complex user systems

"We rarely have a problem that is isolated from others. We need R&D that takes systemic approach to ensure solutions solve challenges in a coordinated and holistic manner."

4 Managing R&D investments across 'inputs' and 'outputs'

"Working out how we get consumers to buy more is not about educating people, it is about how we get them to realise it will be delicious."

"I won't make any investment unless it will mean more sales."

5 Addressing knowledge asymmetries

"Growers don't want to share information with a competitor. What they don't see is that by working together you actually can grow your industry."

6 Collaboration between businesses and tropical and subtropical industries.

"We need to view public-private partnerships with a more open mindset, and share information and discovery across the entire industry."

Insights

Overview

The following insights were developed based on the interviews conducted with researchers, industry and government representatives. These insights are expanded on in the following pages, exploring overarching themes when it comes to the state of tropical and subtropical R&D, the needs of industry, and the general challenges and R&D focus areas these overarching themes are related to.

1

Tropical and subtropical horticulture businesses need to be making decisions now to prepare for the climate of the future. Reliable and clear forecasting tools, with an ability to localise, are required to support businesses and to identify future R&D needs.

2

There is a need to both identify consumer trends that the industry needs to meet in the future (pull products into market) and identify the areas that need to be actively developed and marketed to consumers (push products to market).

3

Building a sustainable business and maintaining lucrative sales contracts requires resilient production systems. The fluctuating availability, skills level, and increasing costs of local and imported labour is adding significant pressures to our growers and jeopardising these contracts.

4

Many R&D solutions are not feasible for growers to implement as they do not fully address the needs of the systems they are disrupting. A systemic approach is therefore required to ensure R&D solutions respond holistically to the users' contexts.

5

The more innovative growers spoke about needing to balance R&D investments across both 'inputs' (ie into production and harvesting activities) and 'outputs' (ie in the marketing and sales activities). Many made the point that while inputs are important, if it ultimately doesn't result in increased sales then it is unlikely they would make the investment.

6

Solutions have the potential for industries to access new markets, both domestically and internationally, and this value could provide growers with additional motivation to adopt solutions.

7

There is a plethora of existing research and solutions across tropical and subtropical industries, and analogous industries. The challenge is ensuring the most promising solutions are clearly communicated to industry, and learning are shared between industry players.

Preparing for climate change

Tropical and subtropical horticulture businesses need to be making decisions now to prepare for the climate of the future. Reliable and clear forecasting tools, with an ability to localise, are required to support businesses and to identify future R&D needs.

A rapidly changing climate and increasingly common extreme weather events are posing major challenges to the horticulture industry. Throughout our interviews, it was clear that this challenge is already being felt. However, across both tropical and subtropical sectors (and a number of other agriculture industries), it is still common to continue existing practises based on current or past weather patterns. This includes crop selection, harvesting decisions, and not adopting innovative science and technologies that could support crops to be more climate and/or pest resistant.

While there may be some forecasting tools that growers can look to, there is a need for climatic model data that can support growers making a myriad of decisions when it comes to adapting to climate change - from what to plant, how to grow it, and when to harvest. The provision of this data, and communication in a way that is understandable and actionable for growers, will be critical.

This modeling would also play a critical role in adoption of innovative solutions, such as the breeding of drought tolerant crops, where growers can clearly understand the value of adopting these solutions. Research into optimal use of fertilisers and water use will also play a critical role in preparing for climate change, especially in climates such as the Northern Territory with long periods without rainfall.

Primary Challenge Areas Addressing

- Climate change adaptation

Main related R&D Focus Areas

- Improved genetics
- Mitigating climate change and seasonality
- Crop protection
- Novel production systems
- Smart propagation

Quantitative Questions

- What current forecasting tools exist to monitor seasonality changes in horticultural production and allow for localisation for use by individual growers?
- What R&D has been conducted to monitor and evaluate the effects of climate change in the future for tropical and subtropical horticulture?

”

“R&D needs to look into what is the best way looking into 2050 to grow each crop in considering the weather and future.”

“Challenge is breeding for the future is difficult because we do not know what to breed for. A big piece of R&D into what the weather would look like and taking that knowledge to understand what direction (think of a system during an extreme winter event - to divert the water)”

“We need to stop making investment decisions for what can be changed now because that will not fix the implications of the future climate.”

”

Understanding consumer preferences

There is a need to both identify consumer trends that the industry needs to meet in the future (pull products into market) and identify the areas that need to be actively developed and marketed to consumers (push products to market).

In Australia, the population is growing and the demographics are changing. Younger generations are becoming more focused on sustainability, grown local, and whole foods, but there is still a knowledge gap when it comes to knowing which produce to buy and how best to consume it. Furthermore, the majority of produce currently grown does not necessarily respond to the growing different cultural/demographic needs in Australia. This is especially relevant for this project, as those who emigrate from tropical countries are seeking a more diverse range of produce than what is currently grown in Australia. Research is needed to understand this changing demographic mix of horticulture consumers and provide that information to growers to ensure they are growing the right crops in the right way. Understanding this could support the creation of new domestic markets, and potentially new export markets.

Work could also be done to encourage people to try new produce/ varieties, and over time transition to more nutritional, and more sustainably grown produce. This will require major consumer education efforts, to support the creation of demand, as opposed to primarily responding to demand. This education would also play a role in the adoption of innovative R&D solutions that may impact the look of produce for consumers, but not the taste. For example, there is currently a solution available to reduce mango burns (and wastage), however, due to the white powder that is left on the mango after harvesting, and concern around consumer reactions to this, there has been minimal to low uptake. Consumer education could support the adoption of R&D solutions such as this, providing benefits across the supply chain.

Collaboration and marketing as a whole of industry rather than segregating sectors would be beneficial, recognising that consumers consume horticulture produce in combination rather than individually (centre of excellence).

Primary Challenge Areas Addressing

- Increasing population
- Diversity of immigration
- Diverse nutritional requirements

Main related R&D Focus Areas

- Human health and nutrition
- Resource efficiency
- Provenance and labelling
- Breeding for testing
- Crop diversification

Quantitative Questions

- What tools can growers currently access to understand consumer needs?
- What solutions currently exist that help growers meet future consumer requirements? Where are the gaps?

"

"How do we better understand current consumer preferences in different personas and nudge people in the right way to make the right choices."

"Our population is growing and horticulture products will play a big role in getting nutrition back to the consumer."

"Our society has diverse backgrounds, and we need to understand what crops they require based on their specific circumstances. Despite carrots and celery being widely available and widely promoted as beneficial vegetables, other cultures prepare meals using different crops. We need to start developing R&D around understanding the demographics, preferences and health benefits of the people consuming our products."

"

Efficient production systems

Building a sustainable business and maintaining lucrative sales contracts requires resilient production systems. The fluctuating availability, skills level, and increasing costs of local and imported labour is adding significant pressures to our growers and jeopardising these contracts.

It is becoming increasingly difficult to source skills within the Australian labour force market, and therefore the industry has had to rely on skilled or semi-skilled migrant workers. However challenges such as visa issues and lack of seasonal migration, as well as worldwide challenges including COVID 19 and border closures, is placing additional pressure on this migrant workforce solution. This, combined with an aging farming population, means that the industry is often met with labour shortages, lack of skilled workers and high labour costs, leading to inefficiencies and systems that are sensitive to market shocks.

R&D in agriculture has acknowledged the need for solutions that address labour shortages. Automation and robotics are a critical part of this, however, the 'system' these solutions exist within need to be considered (further explored in insight 4). Automation, while an important opportunity to address labour challenges, also means that a number of workers may not be able to transition to this new solution, so a fair transition for this workforce needs to be considered. Additionally, while some crops may be ideal for harvesting via robotics, this solution is seen as not applicable to certain crop types (e.g. bananas). However, for these challenging crops, it is essential to explore how collaboration with growers to understand concerns and requirements of technology, combined with ways growers can make decisions to enable the technology (e.g. pruning into a certain shape), could be explored to understand further how novel technologies could reduce labour required for harvesting and processing. Other solutions (such as genetically modifying crops for ideal picking) are just as important to consider.

Primary Challenge Areas Addressing

- Labour shortages/ access to labour
- Costs of labour
- Increased cost production

Main related R&D Focus Areas

- Automation and robotics
- Transformational technologies
- Novel production systems

Quantitative Questions

- Which crops will benefit from automated harvesting? What solutions are currently available to them?
- Which crops are unable to be harvested via technology? What solutions are available and required to reduce labour costs/ challenges for these crops?
- How can post-harvest solutions reduce pressure on harvest outputs?

"

"We need to put more effort in automating things rather than increase labour"

"Labour costs represent over 60% of input costs so we need to look at different ways to increase our labour input and improve our outputs and robotics and automation R&D could be a way to solve this"

"Skillsets we have now in horticulture could change dramatically - if we go into robotics we need a different skill set"

"Indoor pack sheds have now been largely automated and there is labour reduction due to it"

"

Wholistic R&D

Many R&D solutions are not feasible for growers to implement as they do not fully address the needs of the systems they are disrupting. A systemic approach is therefore required to ensure R&D solutions respond holistically to the users' contexts.

While there are multiple innovative solutions currently available to growers, particularly digital/ technological solutions, the impact of these solutions will be limited if they do not respond to the full system in which they wish to operate. The challenges tropical and subtropical crops are facing often require a suite of co-ordinated solutions to achieve tangible results.

For example, in the avocado industry, AI drones could be a valuable tool for identifying optimal picking times. However, the workforce is not flexible enough to respond when the ideal picking time is identified (growers need to schedule this labour well in advance), and therefore without other technological solutions such as automated harvesting, this tool is not feasible on its own. Additionally, for automated harvesting, changing of plant structure is potentially required, and therefore these solutions also need to be explored in tandem with breeding solutions. In this example, it is clear that while the challenges of optimum harvesting and labour issues could be addressed, without a systemic approach, these R&D investments and solutions will not have the desired impact.

This wholistic approach goes beyond the technical - there are also regulatory and legal environments that need to be understood and addressed to ensure R&D outcomes are adopted. For example, there's an opportunity to collaborate with government and Indigenous agriculture organisations to expand horticulture opportunities in the Northern Territory. R&D that de-risks agriculture in these areas, such as alternate land tenure models, could further support the growth of the horticulture sector.

Primary Challenge Areas Addressing

- Labour shortages/ access to labour
- Costs of production / reducing waste

Main related R&D Focus Areas

- Improved genetics
- Transformational enabling Technologies
- Automation and Robotics

Quantitative Questions

- What solutions currently exist that seek to tackle the primary challenge areas in isolation?
- What solutions currently exist across the focus areas which could be combined to solve major challenge areas? Where are the gaps?

"

"Tech is there, but level of appetite is usually low. Some big producers are there and have adopted... but the vast amount of growers really need that clear cost benefit understanding that's currently not provided."

"Out in the field most fruit is picked by humans but will still be for some time - the machines are 10% slower than the human. There is a lack of robustness on that type of technology in the field - the field is uneven, and mud drains that robotics couldn't cope with."

"R&D solutions do not happen in isolation, and therefore a systemic approach is required to ensure R&D solutions solve challenges in a coordinated manner, and holistically solve challenges."

"

Managing R&D investments across ‘inputs’ and ‘outputs’

The more innovative growers spoke about needing to balance R&D investments across both ‘inputs’ (ie into production and harvesting activities) and ‘outputs’ (ie in the marketing and sales activities). Many made the point that while inputs are important, if it ultimately doesn’t result in increased sales then it is unlikely they would make the investment.

As identified through industry interviews, solving challenges on the input side of production (changing the growing conditions of a crop) without focussing on the ultimate output (the quality and taste of the product) is a major pain point when it comes to research solutions. This hinders the adoption of solutions, and creates legacy issues that are difficult to overcome, with growers hesitant to adopt innovations due to “cautionary tales”. Furthermore, while input solutions may be appealing to producers that are interested in reducing pesticides/ fungicides, those that are focussed on fruit quality to meet processor requirements may be hesitant to adopt. If solutions clearly address both input and output needs, they will have a higher impact, and higher chance of adoption by a variety of growers.

For example, if a breeding solution has pest resistance, and therefore requires one application of pesticide as opposed to 10 applications, this has the potential to reduce not only sustainability challenges, but also input costs. However, without it being proven that this process has no negative impact on taste, or ideally that the end product is improved (through clear fact-based information), growers will likely be apprehensive. Understanding and communicating the total impact of an intervention is essential to gain grower buy-in, and de-risk investments in innovations. This information needs to also be coupled with cost-benefit analysis, to support investment if there are high upfront costs, recognising that many growers are highly leveraged and have a low risk appetite for change. It was noted in interviews, that while a solution may be demonstrated to be effective, there are major behavioural and cultural barriers that need to be overcome. Therefore education combined with major extension work to understand and overcome behavioural barriers (e.g. concern around changing on-farm practises) could support solution adoption.

Primary Challenge Areas Addressing

- Improved Genetics
- New Crops
- Human Nutrition
- Mitigating Climate Change and Seasonality

Main related R&D Focus Areas

- Adjusting to a changing climate
- Providing quality fruit to market

Quantitative Questions

- What research is being conducted which addresses both input and output desires of growers?
- Where are improved genetics focussing? What is the split between input and output solutions?
- What models / tools have been built to support ROI / CBA analyses of new options for growers?

“

“Working out how we get consumers to buy more is not about educating people, it is about how it will be delicious.”

“The technology is there but the level of appetite is usually low... data is there for traceability - big producers are there and have adopted it however they need that cost benefit understanding”

“Plant health and the use of chemicals to reduce public health and environmental issues and control diseases (Something individual growers or small companies can't do). It needs to be done collaboratively with all stakeholders.”

”

Accessing new markets

Solutions have the potential for industries to access new markets, both domestically and internationally, and this value could provide growers with additional motivation to adopt solutions.

R&D solutions have the potential to open up new markets, and overcome challenges that previously have limited Australia's ability to compete, especially when it comes to export markets. Australia's use of pesticides is a particular challenge that markets are increasingly intolerant to (e.g. the EU). So is inconsistent supply which can mean lucrative export contracts are lost. Additionally, identified through industry interviews, product quality is a major concern when it comes to competing with tropical and subtropical products on a global scale. Solutions that can tackle issues such as these can therefore impact a number of areas, and provide the opportunity to deliver better quality products, with more sustainable credentials to export markets.

If R&D solutions can be aligned with the demand of growers wanting to access new markets (particularly export) this is another lever that can be utilised to demonstrate the value of solutions and facilitate adoption (e.g. pest resistant crops). This would require a major communications effort to ensure growers understand how these solutions would support the acquisition of new markets now and in the future, especially as market requirements shift and change.

Primary Challenge Areas Addressing

- Provenance and labelling
- Improved genetics
- New Crops

Main related R&D Focus Areas

- Access to export markets
- Fruit quality assurance
- Improved sustainability credentials
- Sustainable, resilient, and consistent production systems

Quantitative Questions

- What are the major export requirements that growers will need to meet now and in the future? What R&D solutions are available that will support the meeting of these requirements?

"

"The industry has major challenges in market access and exports. Currently, a lot of tropical and subtropical fruits coming from Australia are very domestic-based and the production outweighs the amount we export."

"The industry needs a lot of scientific support and intelligence to determine how to mitigate risks when exporting to other countries."

"We are struggling to export internationally due to pesticides. Australia has the worst pests at the moment and we use a lot of pesticides in Australia because we have to due to our pest issues. However, importing countries like China and others are asking for pesticide-free products. This is something we need to solve."

"

Addressing knowledge asymmetries

There is a plethora of existing research and solutions across tropical and subtropical industries, and analogous industries. The challenge is ensuring the most promising solutions are clearly communicated to industry, and learning are shared between industry players.

Throughout the interviews, stakeholders referenced the abundance of solutions available to their industries. Interviewees highlighted that a major challenge currently, is the pipeline of solutions - with many promising innovations struggling to receive funding to demonstrate commercial technology readiness, and that without this proof, many growers will be reluctant to adoption new technologies. So while exploring new interventions is important, there is a significant amount of work and funding required to ensure the most promising existing solutions are effectively trialled and adopted by industry. Interviewees also identified that there is the opportunity to look at analogous industries developing similar technologies to understand their applicability to horticulture crops. For example, the use of robotics for Improvised Explosive Devices (IEDs) by ADF, and how this could be applied to automated harvesting. The use of macrophages for managing infections in medical fields could also be explored in relation to extending shelf life.

Across the interviews, it was highlighted that major knowledge asymmetries exist throughout the industries, and between different supply chain members, limiting the impact of existing solutions. These knowledge asymmetries can exist when benefits are poorly communicated to adopters, or, where competition means companies do not share successes or failures with other stakeholders, limiting the dissemination of learnings and potential advancement of Australian growers. R&D providers need to work actively with industry to ensure this knowledge flows throughout this system. Furthermore, to ensure research is not repeated across various organisations, communication channels between R&D providers needs to be improved. Analogous industries can also be looked to when it comes to information transfer, such as systems for upskilling and knowledge transfer across the global pilot workforce, and how this could be used to share best practice across growers in Australia.

Primary Challenge Areas Addressing

- Labour shortages/ access to labour
- Costs of labour
- Increased cost production
- Post- harvest

Main related R&D Focus Areas

- Automation and Robotics
- Post-harvest

Quantitative Questions

- What are the existing solutions that tackle major challenges, but require additional extension and communication activities to support adoption?
- What are the research gaps that could be filled with solutions from analogous industries?

"

"We'd really need to look at how do we do this more collaboratively. You've got too many players. We need centres of excellence where research is done and sensor mixing working across different fields using expertise across multiple sectors to do good data results."

"I think we're waiting for ag scientists to deliver robotics in agriculture whereas what we really need to be doing is engaging with those who have developed solutions in other industries."

"Growers don't want to share information with a competitor. What they don't see is that by working together you actually grow your industry."

"

Industry Specific R&D takeaways

The following pages explore the findings from interviews with specific crop industries. Each section highlights the current state of R&D in the industry and/or the main challenges they are facing, along with the discussions alignment with the R&D focus areas. The following is not an exhaustive list of takeaways from each industry. As the interview process unfolds in January, a broader perspective will be developed.

Macadamias

Key Takeaways:

- Macadamias are undertaking a lot of R&D at the moment, and there is not a shortage of solutions. Their main challenge is getting the funding to develop and implement solutions.
- They collaborate informally with other tropical and subtropical industries, a co-ordinated approach could help support this further.
- Their needs differ a lot from soft fruits and vegetables. For example, areas such as prolonged shelf life aren't as relevant to nuts as they already have a much longer shelf life. This influences the overlapping R&D needs.
- Meeting processor requirements during situations of oversupply can be difficult, so increasing the quality of macadamias, regardless of the state of the market, would be beneficial for growers.

Quotes from participants:

Softer Chemistries	"We have a lot of R&D going on but could do more on the integrated pest management side of things, especially in regards to softer chemistry. This is also important for social licence."
Digitisation / Automation and Robotics	"Tech is there, but level of appetite is usually low. Some big producers are there and have adopted... but the vast amount of growers really need that clear cost benefit understanding that's currently not provided."
Human Nutrition	"It's hard to make health claims with nuts...and nutrition is good to collaborate with across industries, but there's always the competition factor."

Avocados

Key Takeaways:

- There is a lack of knowledge of the basic physiology of the avocados. The carbon partitioning of the plant, fruit setting, and fruit retention require further research and development. Life cycle assessment of avocado can help the growers define sustainability metrics.
- Only 10% of Australian avocados in 2021 were exported, with Australia struggling to compete with Mexico, Chile and Peru. This struggle to compete is in part due to avocados' high susceptibility to fruit flies in Australia, and therefore R&D that underpins fruit fly protocols is of particular interest.
- While growers believe that Hass is the most preferred avocado by consumers, research needs to be conducted to demonstrate that Hass is not the only choice of consumers and that a wider range of varieties could be grown in Australia.
- Innovation is needed to develop new scion varieties with desired traits and differentiated characteristics, harnessing technologies such as speed breeding by growing in controlled environments and gene editing. These tools and techniques can be utilised across horticultural crops.

Quotes from participants:

Crop Protection/ Improved Genetics	"Phytophthora root rot is currently one of the biggest challenges facing the avocado industry. Additionally, There is a need for chemicals and other interventions to mitigate and manage root rot, anthracnose and other fruit diseases."
Automation and Robotics	"While there is potential for integrating machinery into avocado production, there are also some barriers to overcome. Many avocados are hidden inside the canopy and have the same colour as the leaves, so the machine is unable to identify them."

Industry Specific R&D takeaways

Berries

Key Takeaways:

- The berry industry has benefited from research in developing new varieties with differentiated traits and this area needs continued focus augmented by new tools and technologies.
- A large number of breeding R&D opportunities exist for berries, and continuous improvements can be made to their size, quality and taste in order to satisfy consumer preferences.
- The berry crop offers great potential for indoor and vertical farming. Growers are already adopting these solutions, and many view protected cropping as an important advancement for long-term industry sustainability.
- Clean, disease free, season independent and scalable plant supply of existing and new varieties is needed for increasing productivity and profitability. It is also imperative for new varieties to capture domestic and international markets.
- Crop protection technologies both pre and post-harvest resonating with environmental sustainability and reduced residues are needed for a profitable and internationally competitive berry industry.

Quotes from participants:

Improved Genetics	"Raspberries and blueberries are largely proprietary top genetics there's no breeding for them. There are only a couple of companies around the world that are doing any breeding R&D on them."
Climate change and seasonality	"It is necessary to develop varieties that can withstand extreme temperatures. For instance, Queensland strawberry industries have been breeding varieties that can thrive in our warmer climate for over 20 years. Currently, we have one of the highest yields in the world. As a result, we must continue to improve genetics to produce the highest yield in our climate. "

Bananas

Key Takeaways:

- There is major need for pest control and disease control solutions for the banana industry. For example; in Latin America, currently a third of the cost of production is spent on controlling diseases.
- It is difficult for bananas to compete on a global scale, as they are grown year-round (so don't have a seasonal advantage to other countries), and cannot compete on price due to high costs of production (primarily labour).
- **Robotic harvesting and processing is currently not** feasible for bananas, as there are key challenges relating to bruising, terrain, and the shape of the fruit. New varieties that resolved these issues with robotic harvesting could therefore be very beneficial.
- In general, banana growers tend to grow only one type of banana or only bananas specifically. There have been efforts to diversify banana varieties in the past that have had little success. **New markets for bananas therefore could focus on creating alternate value streams** for out of specific bananas/ oversupply.

Quotes from participants:

Sustainable Production Systems/ Waste Reduction	"Bananas are easy to grow, and there is currently a large amount of production of bananas at lower prices. However, around 30% of the product is thrown into the paddock, so there is a significant amount of waste."
Improved Genetics	"Bananas are hard to breed because they have no seeds, but there are programs doing this around the world...more investment is needed to bring those international solutions to Australia...a resistant variety is really the long term solution to overcoming things like TR4."
Protected Cropping	"Protected cropping is difficult due to the cost of installation...there are hectares of bananas to cover, and this equipment is often uninsurable due to extreme weather (e.g. cyclones destroying netting)"

Mangoes

Key Takeaways:

- Typically mangoes are ripe and ready for market in summer for a period of around three months. An opportunity for future R&D could therefore be to explore how mangoes could be grown and available for market beyond this time frame, and potentially offered year-round.
- While a **number of major corporations are adopting and trialling automation**, providing these solutions in accessible ways to smaller and family run businesses is a major hurdle.
- Strong existing breeding programs, genomic information and established trials with phenotypic data provide an opportunity to fast-track R&D leading to development of new differentiated mango varieties with improved fruit characteristics as well as facilitating automation in orchard management.

Quotes from participants:

Protected Cropping	“Mangoes are a seasonal crop and can only be grown in Australia for a short period of time. There is an opportunity for R&D in indoor and vertical farming techniques to allow for a mango to be grown all year round.”
Improved Genetics/ New Crops	“We have been actively looking for the next variety of 'honey gold', but it does not exist at the moment. The Honey Gold variety of mangoes remains the best variety to delight consumers and be profitable.”
Processing & Alternate Value Streams	“Northern Territory is a really good example. We don't have any food processing. So if a mango doesn't make grade, it doesn't have a second home.... if there was another market that put a floor price in that would get rid of some of that lower quality fruit that doesn't hit the market shores and drag the price down.”

Pineapples

Key Takeaways:

- The pineapple industry has developed multiple varieties with different attributes. Despite this, there is no current variety in the industry that is growing in **all climates and year-round**.
- The other more specific varieties can only grow in certain regions at certain times. As a result of this, their production cost is higher.

Quotes from participants:

Improved Genetics	“Pineapples have been in breeding programs for multiple years and have developed 6 different varieties that have come out from the past 25 years.”
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Thank you!

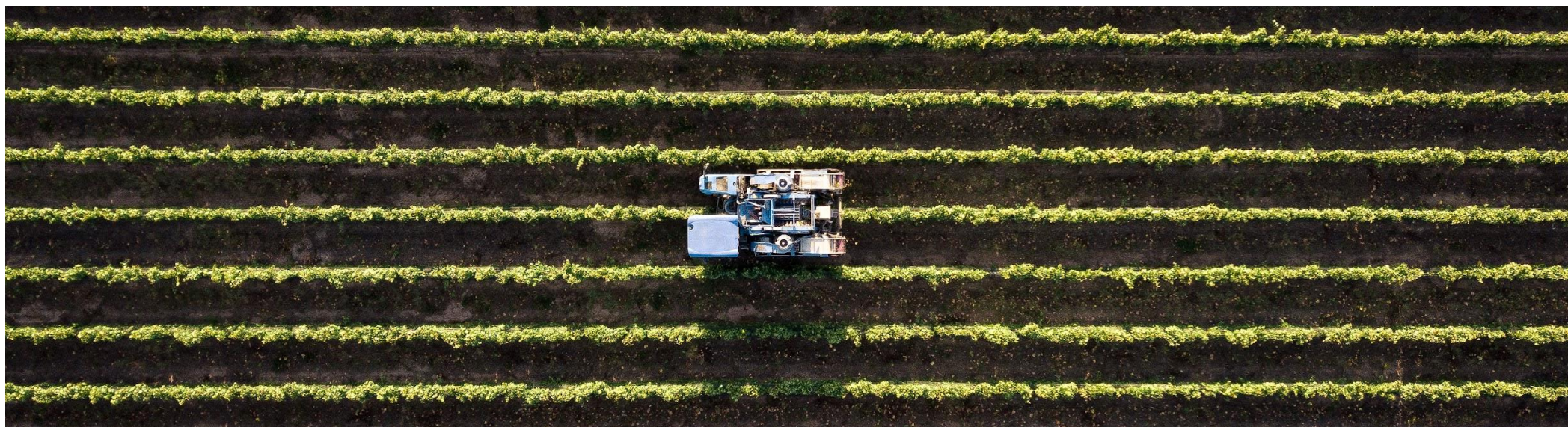
Thank you for collaborating with us on this important project. We look forward to working with you on any future projects exploring transformational R&D opportunities in horticulture.

For any feedback or questions, please contact the project lead:

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Our Values

Purpose

We always seek to understand the why before we define the what. We ensure everything we do delivers against a greater goal.

Diversity

Ideas without action are worthless. We focus on identifying the most valuable opportunities and making them a reality as quickly as possible.

Vision

We see things for how they could be rather than how they are.

Impact

Our global network of experts enables us to ensure the right people are on the right projects, while giving us the flexibility to scale relative to a projects' needs.

The Four Pillars

People over process

We partner with leaders, not organisations. We focus on understanding their challenges and working together in a way that's best for them. There's no one-size-fits-all solution here.

Story-makers, not story-tellers

We demonstrate the value of what we've done in practise, rather than talk about what we do in theory.

Turning insight into action

Ideas without action are worthless. We focus on identifying the most valuable opportunities and making them a reality as quickly as possible.

Collaborative thinking

Our global network of experts enables us to ensure the right people are on the right projects, while giving us the flexibility to scale relative to a projects' needs.

A photograph of a greenhouse interior. In the foreground, a large, round, green melon with a netted texture hangs from a vine. The vine is supported by white strings. In the background, a person wearing a dark jacket and a hat is visible, working among the plants. The overall scene is dimly lit, with a soft, natural light filtering through the greenhouse structure.

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