Final Report

The business of pollination in horticulture

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GHD Group Pty Ltd

Project code:

PH19004

Project:

The business of pollination in horticulture (PH19004)

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Funding statement:

he business of pollination in horticulture is funded by the Hort Frontiers pollination fund, part of the Hort Frontiers strategic partnership initiative developed by Hort Innovation, with co-investment from The New Zealand Institute for Plant and Food Research and GHD Pty Ltd, and contributions from the Australian Government.

Publishing details:

ISBN 978-0-7341-4870-4

Published and distributed by: Hort Innovation

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Public summary

PH19004 – The business of pollination in horticulture is a desktop review of artificial pollination technologies and collection methods paired with a business case on artificial pollination in Australia. This project was funded due to increasing difficulty in achieving successful pollination in several Australian crops, and the uncertainty in the future supply of honey bees for crop pollination.

Desktop analysis and grower interviews

In order to assess artificial pollination technologies that might be used in an Australian context, staff at The New Zealand Institute for Plant and Food Research Limited (PFR) conducted a series of literature reviews on different strategies employed globally to both collect pollen and pollinate crop plants. Pollen collection is generally done by hand-harvesting whole flowers (or catkins or strobili) and milling them for pollen; mechanical harvest is currently only realized for almond and maize. We were able to group the dozens of commercial pollen application offerings (and many more patents and prototypes) into several general categories: handheld devices, backpack devices, tractor attachments, drones, and robotic platforms.

We also interviewed growers across three cropping industries about their pollination challenges and perceptions of the practicalities of these artificial pollination technologies in an Australian context.

Business case

Using the information gathered in the literature review, GHD Pty Ltd (GHD) created a business case for artificial pollination in Australia using three case-study crops: almond (insect pollinated, self-incompatible), olive (benefits from insect pollination, partially self-incompatible), and strawberry (insect pollinated, self-compatible). Technologies requiring labour intensive application had the highest barriers to use, while tractor mounted applicators were the most favourable. Securing a pollen supply will be the primary challenge for the adoption of artificial pollination in Australia. For some crops, it will be possible to harvest pollen on-farm for application, and pollen donor farms may be profitable where mechanical flower harvest is an option (currently almond).

Conclusions

There is a diversity of artificial pollination systems in use globally, of which several would be suitable to Australian conditions. If the barrier to importing pollen can be overcome, pollination of pip fruit, stone fruit, pistachio, kiwifruit and almond would be able to be trialed in the short term. Absent this, tech companies showing particular interest in the Australian almond industry (e.g. Edete, XAG) have self-funded pilot trials. Additionally, collaborations between Australian industry and international pollen collection businesses or research institutes could adapt international practice to local conditions and allow the local collection of pollen for an artificial pollination market.

Keywords

Artificial pollination; mechanical pollination; pollination technology; hive inserts; pollen donor farm; almond; olive; strawberry

Introduction

Most agricultural crops require pollination (either through insects or wind) for successful production. For some crops, such as almond, the demand for pollination services can be extreme in a region during bloom—requiring bees to be transported over large distances to achieve full pollination. With many industries planning to expand, increasing demands are put on the national supply of honey bees. This increased demand results in higher prices per hive paid by the grower, but not necessarily an increase in colonies available for pollination. There are many intersecting issues threatening hive supply during the pollination window: increasingly frequent and severe bushfires destroying hives as well as the resources in the landscape necessary to sustain them, COVID-19-related border restrictions limiting transport of hives between states, and arrival of *Varroa destructor* on Australian soil, which has increased hive rental costs in other countries post-incursion. Likewise, changes in weather patterns and the increase in extreme weather events can disrupt synchrony between the main crop and its pollenisers. It is therefore important to the continuing stability of high-value crop production to have alternate means of pollination available in the event that traditional pollination fails.

Humans have tried to replace natural pollinators before, with varying degrees of success. Date palms have successfully been hand-pollinated by humans for over 4,000 years—documented since at least the Code of Hammurabi (1). Other plants have been more challenging, as most have smaller flowers, less pollen, and a shorter working life for each pollen grain. It is one thing to collect a small quantity of pollen for breeding, a topic which has been thoroughly explored in the literature, and quite another to collect sufficient pollen to provide supplementary pollination or full replacement of insect pollinators. Even in cases where such efforts have been successful—such as the famous human pollinators of Maoxian County in China where a massive force of labourers hand-pollinated vast tracts of apples with paintbrushes (2)—they do not always remain so. When the area was visited again by researchers after 10 years, the apple trees had largely been cut down and replaced by the wind-pollinated walnut and self-fertile loquat, which are capable of pollination with few or no bees (Partap and Ya 2012). The situation arose because the high use of pesticides created an environment where beekeepers refused to risk their hives, but the loss of labour force to the cities made the practice uneconomical over time, even with low labour costs. Increased mechanisation is needed to make the practice viable.

A handful of industries—stone fruit, pip fruit, and kiwifruit chief among them—have several decades behind them of successful pollen collection and application, using a wide array of pollination technologies, from hand applicators through to tractor mounted spray systems. Anecdotally around 50% of New Zealand kiwifruit growers apply supplementary pollen to their crop; supplementary pollen can improve crop yield and helps mitigate risk in this important production step. Pollen is typically applied by broadcast application, however we are involved in various research projects to autonomously fully pollinate crops. This work was demonstrated in field trials in 2017 and 2018 with a mobile platform travelling at 1–2.5 km/h that used stereo vision and neural networks to locate kiwifruit flowers and trigger targeted delivery to individual flowers (3). This work is ongoing with a number of challenges to be overcome for practical commercial application. The fact that these and similar practices are implemented in countries like South Korea, Italy, the United States, and New Zealand, where the cost of labour is high, speaks well for the potential for similar techniques to be used for other cropping systems, and indeed, pollen for several crop species is available commercially for this purpose. However, importing pollen is not without its own biosecurity risks (as is suspected to have been involved in the incursion of the disease *Pseudomonas syringae* pv. *actinidiae* into New), and developing a local production system is an essential component in ensuring resilience in the face of uncertain local and global conditions.

In order to ensure consistent pollination of high-value crops in the face of potential pollinator shortages, and to be able to expand horticultural industry beyond the capacity of the landscape to support honey bee colonies (and wild pollinators), it will be necessary to investigate how Australia can collect and apply pollen in ways that make efficient use of human labour and are suited for Australian conditions. For the successful uptake of these pollination technologies in the Australian market, a strong business case needs to be developed along with a clear understanding of industry readiness. The potential benefits of mechanical pollination technology would be shared across a number of horticulture sectors and growing regions; therefore, a coordinated approach is required.

Methodology

Objective 1: Pollen collection systems

The New Zealand Institute for Plant and Food Research Limited (PFR) conducted a review of pollen collection systems globally by searching across multiple literature databases including ProQuest and Google Scholar and a patent database. Results were combined and duplicates removed with a fuzzy matching algorithm. We also interviewed businesses and individuals involved in pollen production in New Zealand, the US and Israel to get further information on pollen collection strategies. From these diverse data, we identified methodologies global pollen providers are using to obtain their pollen. Any mentions of artificial pollination technologies will be saved for Objective 2.

For each pollen collection system, we collected the following:

- The maturity of the system (in development, experimental, small-scale commercial, large-scale commercial);
- Where the system is currently employed;
- What crops it is employed for presently;
- What crops it could potentially be employed for without modification; and
- Approximate labour requirement and costs

Objective 2: Artificial pollination technologies

PFR conducted a review of artificial pollination technologies, delivering key inputs to GHD for the formulation of the business case. As emerging technologies are often skipping scientific publication and going straight to market application, our review of this area included ProQuest and Google Scholar, a patent database, and also expert knowledge and connections to industry, researchers, grey literature, and popular press articles. For popular press articles, we assessed which of these emerging technologies were only laboratory prototypes, and which ones appear to be ready for field deployment at the time of the review, and for which crops. This review also assessed the applicability of these technologies to key Australian crops based on knowledge around floral morphology, pollen production, and pollen storage techniques.

For each artificial pollination technology, we examined:

- The maturity of the system (concept, prototype, near-to-market, small-scale manufacture, widely commercially available);
- Where (if anywhere) the system is currently employed;
- What crops (or targeted crops) is the system designed for;
- What crops could the unmodified technology be realistically used for;
- Key requirements (labour, equipment, gantry arms / rails, battery systems, Wi-Fi, pollen, cost if known etc); and
- For mature technologies, the reported benefit of using the technology vs. control (no pollination) and open pollination with bees

We summarised the above as broad classifications of artificial pollination technologies, which could then be used for economic analyses.

Objective 3: Barriers to adoption

Given material from the technology overview provided through Objectives 1 and 2, GHD completed a rapid analysis of the opportunities and barriers to the adoption of these technologies for key Australian crops. This analysis considered how suitable these technologies are for adoption in Australia, based on: suitable crop types, suitable production systems, technology affordability, technology availability, labour efficiency, supporting inputs and infrastructure (including external pollen), demonstrated yield benefits, and regulatory barriers.

Objective 4: Business case

As it was not feasible to develop a business case for every Australian cropping system, we selected three case study examples of how artificial pollination might be used in Australian horticultural crops, based on international experiences. Where information is available, the case studies provide indicative costs and breakeven yield responses. The three case studies were selected to represent crops with different pollination needs:

- almond (self-incompatible, insect pollinated)
- olive (partially self-compatible, wind pollinated), and
- strawberry (self-compatible, insect pollinated)

An overall situation analysis was completed for a wider range of Australian crops, including yield benefits, pollen supply, potential on-farm artificial pollination business models, pollen handling requirements were assembled using the information from the literature reviews and interviews with industry experts. PFR engaged with Australian stakeholders to develop an understanding of the readiness for adoption of emerging mechanical pollination technology. Growers from each of the three case study industries (almond, olive, and strawberry) were interviewed about their current pollination needs and willingness to adopt new pollination technologies. PFR and GHD also interviewed pollen producers and researchers and companies involved in artificial pollination technology.

Grower case studies

For each case study crop, a GHD explored the on-farm feasibility of artificial pollination for each of the three case study crops. The case study selected an appropriate pollen application business model for the crop, and considered pollen supply, technology costs, labour costs, infrastructure requirements, and other on-farm costs. The estimated cost of applying pollen on-farm in Australian conditions was then translated into a minimum yield response to justify the costs. This value was then compared to literature reports of the yield response to artificial pollination.

Pollen donor farms

Pollen collection methodologies identified in the literature reviews and industry interviews were assessed for the Australian market. An overview of collection technologies and their operational requirements was constructed for the three case studies. For each case study, we considered: the business model, required infrastructure and equipment, labour requirement, capital requirements, any regulatory barriers, and current incentives.

GHD then developed a roadmap for adoption of mechanical pollination. Through the feedback received through the stakeholder analysis and review of technologies, we highlighted pathways to overcome the barriers to adoption identified in Objective 3. We expect the roadmap to match crop type or production system with best-fit pollination innovation types and address the key barriers to adoption.

Our assessed outcomes are provided in the report as graphs, tables, net present values, and a benefit cost ratio. The risks around the stated outcomes are explained and measured where possible.

Results and discussion

We present here a summary of the results of the literature review and business case. The findings of this literature review are described in detail in the scientific paper included in the Appendix (embargoed until publication). The full business case is available in the Appendix.

Objective 1: Pollen collection literature review

A number of technologies for collecting pollen for artificial pollination was found, summarised in Figure 1. In general, commercial operations harvest flowers and then mill them for pollen, but for some crops (particularly if wind-pollinated), there have been reports of pollen successfully being vacuumed from flowers at rates of up to 200g per hour (4). Pollen directly vacuumed from flowers is consistently more viable than that collected through other methods (5, 6). Bee-collected pollen is much less expensive to collect for insect-pollinated crops, but without careful post-processing, the viability of this pollen can be quite low as honey bee pollen pellets contain compounds which inhibit germination (6-8).

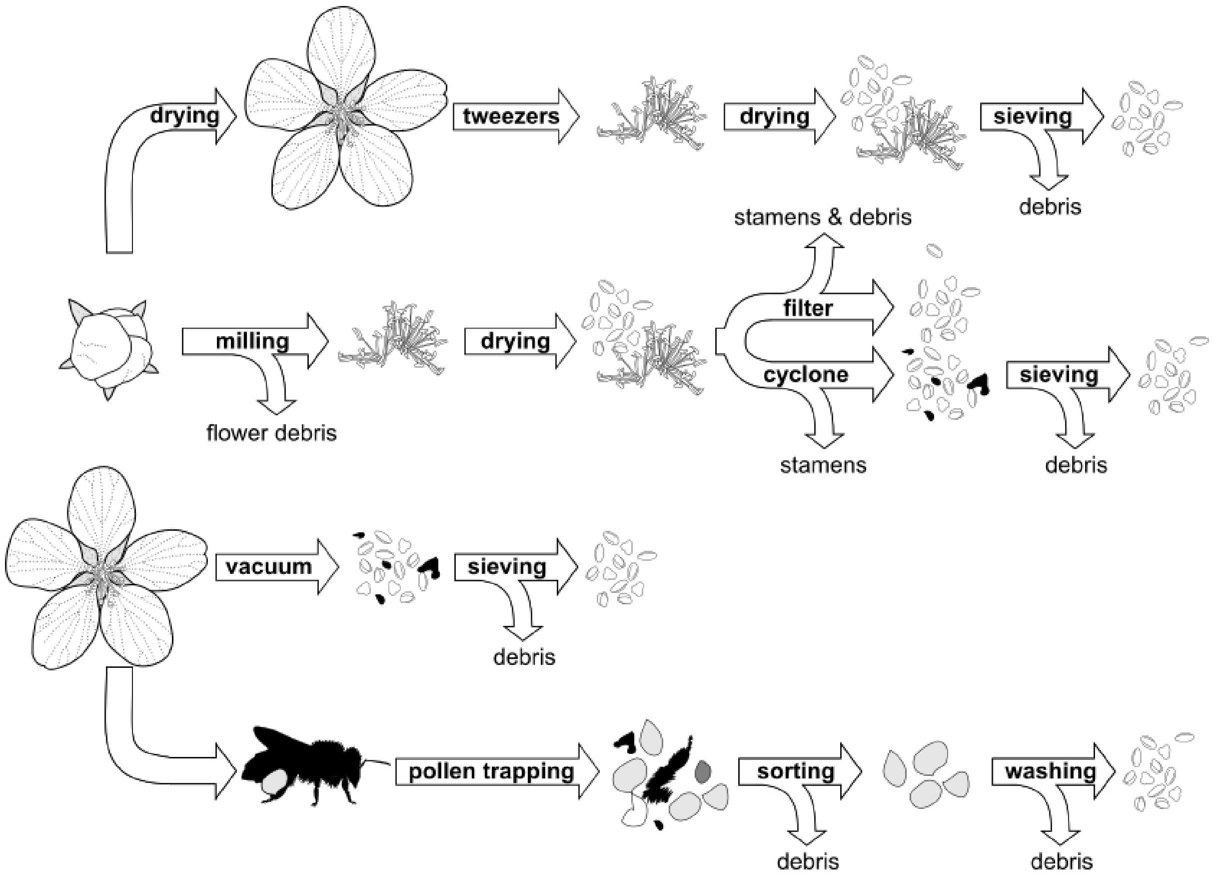

Figure 1: Different processes for extracting pollen from entomophilous flowers for artificial application. Illustration by Melissa Broussard, The New Zealand Institute for Plant & Food Research Limited.

Mechanical flower harvesting is a reality only for maize and almond pollination. For maize, pollinators with machine vision are able to selectively harvest tassels, which can then be extracted for pollen and used for precision hybrid breeding (9). For almond, pollen producers and agritech companies (e.g. Edete) use tree shakers to collect flowers for milling (10). For other crops, including closely related rosaceous tree crops, manual collection of flowers, catkins, or strobili is required. Many patents have been filed in this space in the past 10 years, and mechanical flower harvesting has attracted significant venture capital, particularly in the space of precision flower thinning, where thinned flowers can then be milled for pollen (11).

The findings of this literature review are described in detail in the scientific paper included in the Appendix (embargoed until publication).

Objective 2: Artificial pollination literature review

There is increasing interest in artificial pollination technologies, with large numbers of patents on these technologies issued in the past 10 years (Figure 2). The identified technologies can be divided into three classes: vibratory/contact-based, dry application, and wet application. Technologies that use vibration or contact work for self-compatible crops (e.g. strawberry, tomato) and rely on the flower's own pollen, while the other two types require an external pollen source. These technologies span a wide range of complexity, from simple handheld devices, to backpack devices, to tractor drawn and robotic inventions (Figure 3).

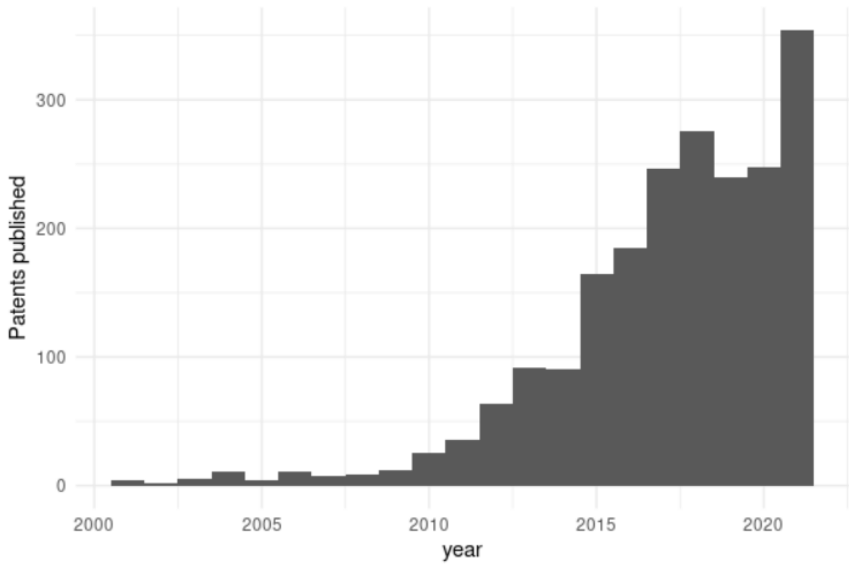

Figure 2: Number of patents published for artificial pollination devices worldwide per year between 2001 and 2021. From Broussard, Coates (12).

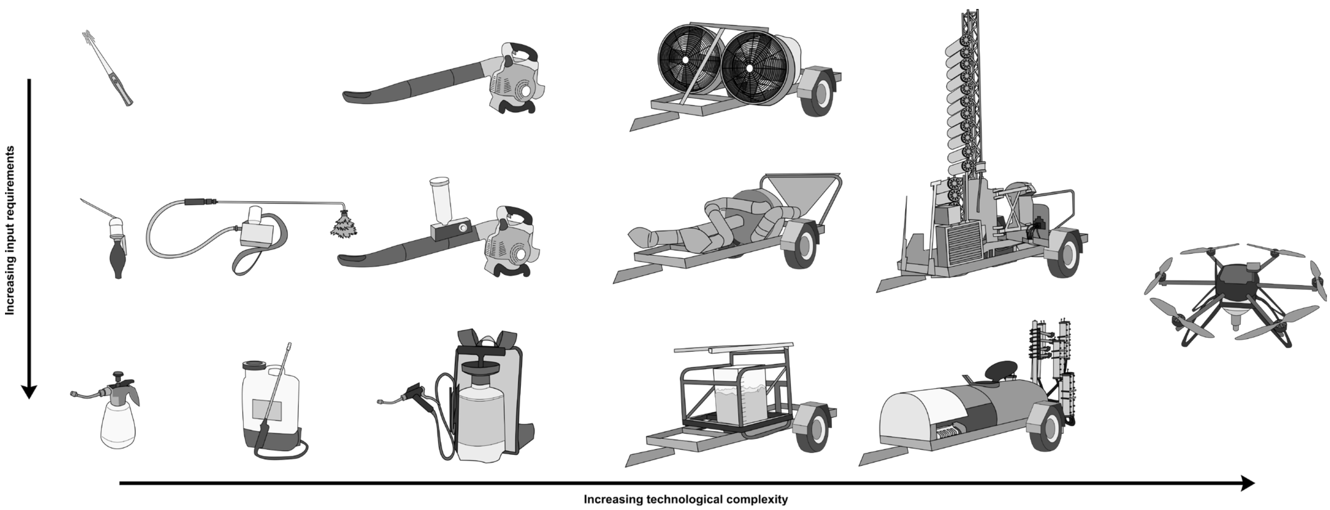

Figure 3: Diagrams of examples of commercially available pollination technologies. Top row: vibratory technologies requiring no external pollen. Middle row: dry-application technologies requiring pure pollen and (optionally) diluent powder. Bottom row: wet-application technologies requiring pollen and a compatible carrier solution. Illustration by Melissa Broussard, The New Zealand Institute for Plant & Food Research.

We found that a majority of artificial pollination systems examined in the literature have been used to supplement insect pollination. However, these technologies were successful in achieving full pollination alone for kiwifruit (3, 4, 13-17), olive (4), date palm (18), walnut (19, 20), tomato (21), and hybrid maize seed (9).

Handheld and tractor-drawn devices are commonly used in commercial operations on-farm, though an increasing number of drone and robotic prototypes are being used in the field. Edete is trialing an electrostatic sprayer for Australian almond production, XAG is trialing a ground-based robotic sprayer for Australian almonds, and AruggaAI is trialing its tomato pollinator in Australian glasshouses. There are additionally prototypes for date palm, kiwifruit, apple, cane berries, indoor strawberries, and a range of other crops.

The findings of this literature review are described in detail in the scientific paper included in the Appendix (embargoed until publication).

Objective 3: Barriers to adoption

Technologies for the delivery of pollen range from handheld or pack devices, tractor attachments, drones or robotic platforms. Supplemental pollen can also be placed at the exit of beehives, where it is collected as they leave and distributed during foraging.

For many of these technologies, the lack of commercial pollen in Australia is a potential barrier. To date only small amounts of pollen have been imported into Australia for horticultural breeding programs, while attempts to import larger amounts of pollen have failed to clear customs. The importation of pollen into Australia is not prohibited, but potential biosecurity risks (especially viral, bacterial, and fungal pathogens) would need to be addressed for the trade of commercial quantities to commence. This may require testing, treatment or assurances. Another challenge for exporting pollen is the need to maintain produce at sub-zero temperatures through the supply-chain.

Australian industry could be well served by establishing secure pollen supply chains through both importation and local collection. In the longer term, opportunities may also exist for Australia to export pollen. The establishment of an initial trading partnership with established international pollen collection companies in the US or New Zealand could be a precursor to developing local collection operations, drawing on international knowledge and expertise

The advantages and barriers to adoption of pollination technologies are summarised in Appendix A of the full business case report. Tractor-drawn attachments were particularly acceptable to Australian growers, followed by drones (Table 1).

Table 1: Acceptability of technologies

Grower	1	2	3	4	5	6	7	8
Industry	Almond				Strawberry		Olive	
	Acceptability of pollination technologies							
Hand-pollination	maybe	no	no	no	no	no	no	no
Handheld and backpack devices	maybe	no	no	no	no	no	no	no
Tractor attachments	yes	yes	yes	yes	yes	maybe	maybe	yes
Drones	maybe	yes	yes	no	yes	yes	maybe	yes
Robotics and autonomous platforms	maybe	yes	yes	maybe	maybe	maybe	maybe	maybe

Grower preference for any given technology is influenced by the conditions under which it is available to them, with a strong preference across growers we interviewed for a full ownership model (Table 2).

Table 2: Acceptability of different business models

Grower	1	2	3	4	5	6	7	8	Average Score
Industry	**Almond**				**Strawberry**		**Olive**		
	Preference Rating of Pollen Supply Business Model (1 = least preferred, 5 = most preferred)								
Full ownership	5	4	5	3	2	5	5	5	4.25
Equipment rental	2	3	1	3	3	4	3	1	2.5
Fee-for-service	2	2	1	4	4	1	3	1	2.25

Objective 4: Business case

Grower case studies

Almonds

Almond growers choosing to mechanically apply pollen will incur costs from pollen purchase (or internal supply) as well as application costs. This study estimated that an almond orchard adopting artificial pollination (applied using a tractor-pulled electrostatic sprayer) would incur additional costs in the order of $1,062 per ha.

Table 3. Indicative pollen application costs

Cost item	Estimate ($/ha)	Assumptions
Pollen purchase	$850	50 g / ha @ $18 per g
Equipment depreciation	$88	Electrostatic sprayer and tractor
Equipment R&M	$19	2% of purchase cost
Fuel	$45	Calculated
Labour	$60	2 hours per ha @ $30 per hour
Total additional costs	**$1,062 per ha**	

Figure 4 below shows the change in gross margins (net margins) from adopting supplemental artificial pollination in almonds, depending on the yield response and farmgate price. This analysis used a baseline yield of 3.5 tonnes per ha reflecting the Australian almond industry average (Almond Board of Australia, information supplied). The analysis suggests that growers require a yield response of 3.5–5.5% to justify artificial pollination (breakeven yield). This finding is broadly comparable with consultation findings from the US almond industry (pers. comm. David Kee). A typical yield response of 7–10% in almonds could increase grower gross margins by around $1,000 to $1,700 per ha, assuming a farmgate price of $7/kg.

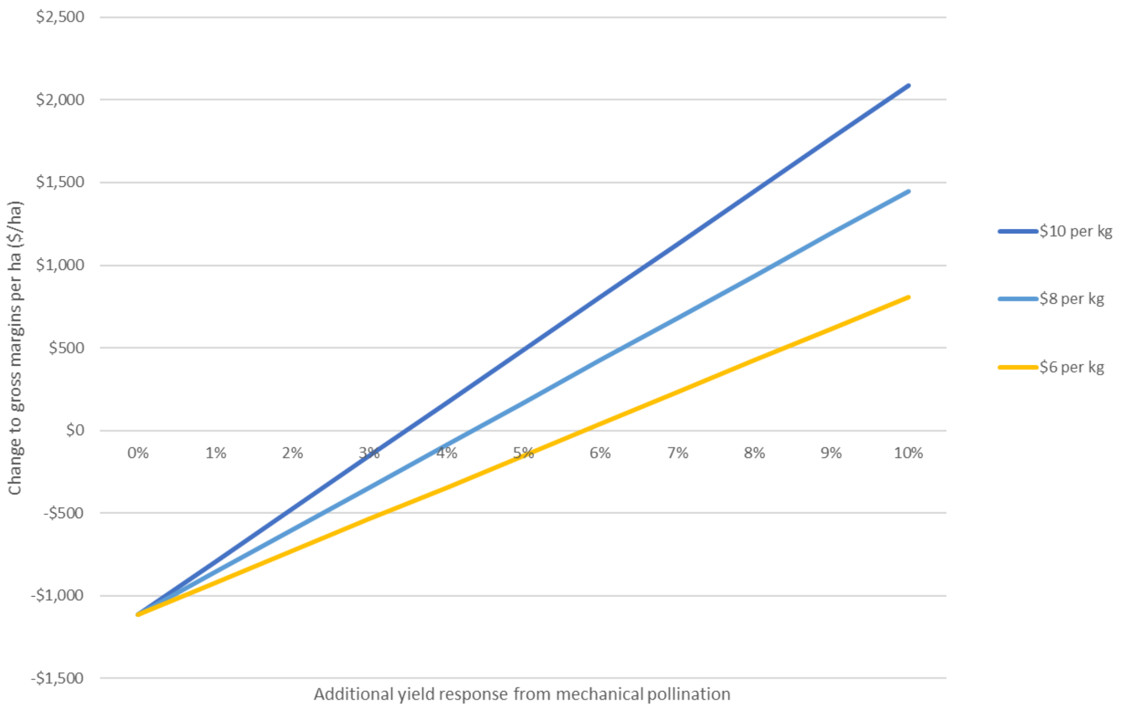

Figure 4: Margins ($/ha) from artificial pollination of almonds, by yield response and farmgate price

The analysis suggests that artificial pollination offers a potential means for Australian almond growers to lift profitability, particularly during poor bee pollination seasons or when contract hives are expensive or difficult to source. The results are largely modelled from conditions and outcomes within the Californian almond industry and assume that Australian almond growers could have access to pollen of similar quality and price, and achieve similar yield responses.

Similar methodology could be applied to Australian pip fruit and stone fruit, which have an established artificial pollination industry overseas (12).

Olives

Olives are a partially self-compatible, wind-pollinated crop. In the past Australian olive growers have intermittently used tractor-drawn fans or blowers to simply provide additional wind to help dislodge and circulate pollen within the orchard canopy. Opportunities may also exist for olive growers to collect pollen using vacuum equipment and immediately re-apply to flowering crops. This has been shown to significantly increase yields in Europe (4).

Table 4 below provides a break-even analysis for the use of vacuum pollen collection and fan application on Australian olives. Assuming a typical yield of 6.12 tonnes/ha and price of $1,240 per tonne (Hort Innovation 2021), Australian olive producers would require a 6.2% increase in yield (or 376kg extra olives per ha) in order to justify the additional cost of vacuum collection and fan application ($467/ha).

Producers choosing to just use fan circulation (without collecting and applying additional pollen) would only require a yield response of 0.45% (27kg of extra olives per ha) to justify the additional cost of fan circulation ($34/ha).

Table 4: Breakeven analysis

Parameter	Value	Unit	Source
Baseline yield	6.12	t/ha	Hort Innovation 2021
Farmgate price	$1,240	$/t	Hort Innovation 2021
Baseline revenue	$7,586	$/ha	Calculated
Additional costs for mechanical pollination			
Vacuum collection + fan application	$467	$/ha	Calculated
Fan circulation only (no collection)	$34	$/ha	Calculated
Break-even olive yield response			
Vacuum collection + fan application	6.2% (376kg olives/ha)	%	Calculated
Fan circulation only (no vacuum collection)	0.45% (27kg olives/ha)	%	Calculated

Early trials indicate yield response from of the above artificial pollination methods are promising, with yield response above our threshold of 6.2% has observed in both 'on' and 'off' years as well as when polleniser cultivars fail to bloom synchronously (4, 22), but not when pollenisers are adequately flowering and spaced throughout the orchard (22). Additionally, when polleniser synchrony is poor, application of collected pollen can be the difference between no crop and above-average regional yields in years with poor synchrony between cultivars (4). The above high-level analysis supports the use of fan circulation of olive pollen as a simple, low-cost method of promoting pollination. Vacuum collection and application involve higher labour and fuel costs, which would be justified if results in Australian conditions are similar to those obtained it Italy and Mexico.

Similar methodology could be applied to pistachio, hazelnut, and walnut, which have each seen promising trials in artificial pollination overseas – with electrostatic application resulting in particularly high yield response (12).

Strawberries

Strawberries are self-compatible but also benefit from insect pollination. Flowers need 10–16 honey bee visits to be effectively pollinated and growers typically introduce additional hives during pollination periods to supplement wild bee populations (23).

Artificial pollination of strawberries has largely been investigated in fully indoor controlled environment agriculture (CEA) production systems. Several robotic prototypes have been developed which use a variety of methods (air jets, ultrasonic vibration, direct contact) to pollenate strawberries (12). These technologies are promising, as none require pollen as a direct input, however no yield response data were available for this study to validate effectiveness. Robotic pollinators are likely to become more available and cost-effective for Australian growers in the coming years. Conversely, contract beehives are expected to become less available and more expensive, prompting increased interest from strawberry growers in adopting the technology.

Prototype robotic systems are in development for other self-compatible crops grown in protected systems, particularly cane berries and tomato (12). One of these, AruggaAI, is being trialed in Australian glasshouse tomato production. As these prototypes are rolled out, more information will become available about their yield responses and economic feasibility for Australian growers.

Pollen donor farms

The commercial viability of pollen supply operations is largely dependent on the rate at which pollen can be collected and the associated labour costs. Pollen collection rates vary significantly between crop types depending on physiology (e.g. the amount of pollen produced) and the suitability of mechanical collection techniques.

Kiwifruit pollen is typically hand collected at a rate of around 1g per hour, which is likely to be similar for other rosaceous tree crops (pers. comm. Mat Johnston, No. 1 Road Pollen). This method of collection is somewhat financially viable in the

US and New Zealand, however unlikely to be financially viable in Australia with higher labour costs. At the other end of the spectrum, olive pollen can be vacuum collected at a rate of 100–200g/h (Gianni et al. 2018), however it is typically re-applied by olive growers at similarly high rates, with limited opportunities for commercial pollen suppliers.

Almond pollen can be collected using tree-shakers at an estimated rate of between 30–60 g/hour (assuming around 3–4g/tree and 10–20 trees per hour). Pollen supply companies in the US and New Zealand typically use casual labour working in small teams to collect almond pollen from contracted properties during flowering periods. The analysis below explored the financial viability of applying this internationally successful business model in Australia. While the analysis was based on the mechanical collection of almond pollen, the findings may be considered indicative of other orchard crops, should similar mechanical collection methods become established.

This study modeled the indicative financial costs and returns for a small-scale pollen supply business, undertaking pollen collection (from contracted properties), processing and selling direct to growers. Based on the above assumptions, this small enterprise could deliver annual profits (EBIT) in the order of $811,000 per annum, repaying loan capital in year 4.

Table 5, Cash flow ($,000)

Year	1	2	3	4	5
Pollen collected per year (g)	81,000	81,000	81,000	81,000	81,000
Sale price ($/g)	$18	$18	$18	$18	$18
Total Revenue	**$1,458**	**$1,458**	**$1,458**	**$1,458**	**$1,458**
Total Costs	**$647**	**$647**	**$647**	**$647**	**$647**
Earnings before interest and tax (EBIT)	**$811**	**$811**	**$811**	**$811**	**$811**
Net Profit After Interest and Tax ($‘000)	**$535**	**$555**	**$576**	**$597**	**$608**
Dividends after loan repayment ($‘000)	**$-**	**$-**	**$-**	**$307**	**$608**

Outlined below are the break-even values required to repay the business loan within 10 years.

Table 6. Breakeven value to repay loan within 10 years

Parameter	Assumption	Break-even Value
Pollen sale price ($/g)	$18	$13
Pollen collection rate (g/h)	45	30
Collection days (days per annum)	20	13
Payments to donor landholders ($/tree)	$5	$21

The results above indicate that a small-scale pollen collection and supply business servicing local almond growers could be financially viable, dependent on market demand for pollen being established amongst a small number of growers. A larger scale pollen supply business is likely to similarly viable, provided sufficient market demand exists.

Economic benefits from establishing domestic pollen supply industry

The analysis below suggests that if artificial pollination was adopted in Australian orchard crops, net economic benefits would be in the order of $5.4m to 12.3m per annum generated through increased grower gross margins and profits returned to pollen supply companies. The analysis presents an upper and lower bound estimates of economic benefit based on different levels of adoption within suitable orchard crops.

Table 7. Annual economic benefits from niche adoption of artificial pollination in suitable Australian orchard crops

	Lower bound estimate 10% uptake in almond crops only ($m)	Upper bound estimate 10% uptake in all suitable orchard crops ($m)	Assumptions
Increased grower gross margins	$4.0	$9.0	Assumes artificial pollination delivers equivalent returns as modelled for almond producers in this study ($680 / ha based on 8% increase in yield from 3.2 t/ha baseline, $7/kg farmgate price, $1,112/ha application costs
Pollen supply company profits	$1.4	$3.2	Average annual business dividends over 10-year investment period (after interest, tax and loan servicing)
Total	**$5.4**	**$12.3**	

Achieving the above level of adoption is likely to require additional government and/or industry research, development and extension (R,D&E) to overcome knowledge gaps and drive adoption. Without this investment, adoption will be reliant on private investment from international pollen supply companies, equipment manufacturers and individual growers.

This study included a high-level indicative analysis of potential return from R,D&E investment. Under the above modelled scenarios, the modelled return from RD&E investment ranged between 6.4 to 14.5 (BCR).

Outputs

Table 8. Output summary

Output	Description	Detail
Review of pollen collection strategies & review of pollination technologies	Scientific paper reviewing pollen collection strategies and pollination technologies intended for researchers and practitioners in the rapidly changing artificial pollination space	In review. Will publish open access for maximum visibility to researchers, tech companies, and growers
Stakeholder interviews	We conducted grower interviews and pollination tech interviews to inform the business case	Summarised in tables in the business case full report (in appendix)
Business case	Full business case for artificial pollen application to farms and pollen donor farms. Intended for growers and industry bodies	Available as appendix to this report

Outcomes

Table 9. Outcome summary

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
Increased awareness of artificial pollination technologies across several horticultural sectors. Increased ability of growers to compare and assess technologies for suitability within their own operation.	Development of increased access to alternative pollination options	Following stakeholder consultation, key industries are now aware of current agritech interest in Australian crops (predominately almond) and trials being conducted. The business case contains detailed information for growers on what techniques are being practised (and in what crops) globally. Pollen importation highlighted as a potentially serious barrier to uptake in absence of targeted extension activities around collecting and storing pollen	Business case, Feedback from stakeholder meeting

Monitoring and evaluation

Table 10. Key Evaluation Questions

Key Evaluation Question	Project performance	Continuous improvement opportunities
Does the business case adequately lay out possibilities for artificial pollination across the three target industries in Australia?	The business case suggests that there are good options for almond pollination from external sources, that olive (and other wind-pollinated tree crops) could be artificially pollinated on-farm, and that technology is not currently mature enough for strawberries and caneberries (though tomato pollinating prototypes exist)	Extension activities to growers from international agencies with experience (e.g. pollen supply companies, research institutes, pollination tech companies) may help grow knowledge about performing artificial pollination on-farm. Additionally, working to reduce barriers to importing pollen or working jointly with pollination tech companies could help start the industry in Australia
How relevant is the final business case to the selected horticultural industries?	The business case is principally relevant to rosaceous tree crops and wind-pollinated horticultural crops.	Limited technology is available for strawberries and other berryfruit at the moment. Several growers fed back that they do not tend to have pollination problems in berryfruit, suggesting that effort may be better spent elsewhere, with the exception of berryfruit going under cover or fully indoors, where honey bees tend to perform less well
Were representatives from selected horticultural industries successfully engaged in reviewing the business case?	We successfully had representatives from the almond industry, other rosaceous tree crops, and berryfruit, but not olives	Artificial pollination in traditionally wind-pollinated crops is just starting to be explored due to lack of polleniser synchrony, and differential weather effects on main crops and pollenisers. Having a back-up in case of pollination failure is important for these crops as well as insect-pollinated crop – it may be good to start raising awareness now in advance of pollination failure
Have the results of the project been provided to stakeholders who participated in the interview process?	Stakeholders have received results of the interviews they participated in and, in several cases, received draft texts of their responses to review. They will be notified that this report is available after submission	

Recommendations

This study has identified opportunities for artificial pollination to be adopted in the Australian horticultural sector, particularly in suitable orchard crops (almonds, apple, olive, cherry, nectarine, peach, pear, walnut, hazelnut, pistachio and kiwifruit). International experience suggests that artificial pollination offers demonstrable yield benefits particularly in poor pollination seasons.

The current lack of established pollen supply is a clear barrier to the adoption of artificial pollination in Australia. Higher labour costs will likely limit the viability of hand pollen collection in Australia, however ongoing advances in mechanical collection technology will likely create commercial opportunities for the establishment of pollen supply and pollination services, similar to those which exist overseas. The pollen collection and milling equipment could be readily purchased locally or imported. Commercial arrangements could be established with growers to collect pollen from their pollenising trees while establishing supplementary in-house pollen supply orchards (if needed). On this basis, a newly established pollen supply enterprise could begin marketing pollen to Australian growers within a short period (6–12 months).

The main challenge for a new pollen supply enterprise would be to overcome the lack of technical knowledge and expertise within Australia with regards to pollen collection, processing and application. A new enterprise would need to test and refine the processes as well as educate growers on how to handle and apply pollen for best results.

Key knowledge gaps

This study has identified the following knowledge gaps which will need to be addressed to drive uptake of artificial pollination in Australian horticulture:

1. **Yield benefits in Australian horticultural systems:** Internationally, it is generally accepted that using artificial pollination to supplement bee pollination delivers additional yield benefits; however, trial results vary considerably by crop/variety type, production year and methods used. These factors may influence the effectiveness of artificial pollination in Australian production systems.
2. **Grower understanding of artificial pollination techniques:** Australian growers lack knowledge and understanding of how to handle and apply pollen for optimum results. Growers may also need to be educated in how to use artificial pollination as a means of insuring against poor flowering or pollination.
3. **Optimal technologies, methods and service delivery for Australian horticultural industries:** Internationally there are a multitude of technologies, methods and service delivery models for pollen collection and application. In many cases the knowledge and intellectual property behind certain approaches is protected by international pollination and technology providers. Without an established pollen industry in Australia, local growers have limited information or case studies demonstrating the most appropriate approaches for their situation.
4. **Opportunities to import pollen:** Small amounts of pollen have been imported to Australia for breeding purposes (pers. comm. Ben Brown), but larger amounts for artificial pollination have not. Building on existing industry experience and testing for relevant pathogens, the importing of pollen from overseas seems possible. Supply chain delays and maintaining the cold chain have been identified as significant issues, but US pollen suppliers have overcome these challenges and are exporting pollen to various countries, and believe that supplying Australia should be feasible and cost-effective.

Recommended next steps

The adoption of artificial pollination in Australian horticulture could be progressed by addressing the above knowledge gaps, in particular determining how different techniques perform in Australian crops and conditions. This work will help remove risks and barriers for international technology and service providers (as well domestic start-ups) seeking to enter the Australian market. Addressing these knowledge gaps will also make Australian producers more open to adoption.

Pilot facilities and field trials could be established in partnership with private service providers, to explore and demonstrate the feasibility of artificial pollen collection and application techniques in Australian horticultural systems. Trials should seek to address identified knowledge gaps by demonstrating to growers the likely yield benefits in Australian horticultural systems; how to handle and apply pollen for optimum results; and optimal technologies, methods and service delivery for Australian horticultural industries.

An ideal program might involve an Australian research organisation or industry-led organisation partnering with an established international commercial pollen collection company to pilot local pollen collection, storage and application. Such a program would leverage the knowledge and intellectual property within international pollen collection companies, while testing for local factors (differences in climate, crops, production systems, infrastructure, grower equipment and knowledge).

The establishment of initial partnerships with established international pollen collection companies in the US or New Zealand could be a precursor to developing local collection operations, drawing on international knowledge and expertise. Joint venture, franchising or licensing agreements could be used to bring international proprietary methods and technologies to the Australian market.

Initial efforts could focus on almonds, before being extended to other suitable crops once the value proposition has been established.

Refereed scientific publications

Journal article

Broussard, M., Coates, M., Martinsen, M. 2023. Artificial pollination technologies: a review. Agronomy. In review.

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Intellectual property

No project IP or commercialisation to report

Acknowledgements

We would like to thank Aran Sisley, Nico Bordes, Samantha Butler and Claudia Adams for providing background economic analysis and assisting with the patent search; Toni White for assisting with the development of interview questions; Andrew Granger, Peter Cook, and Michael White for their assistance in formulating this project; Ashley Zamek, Warrick Nelson, Monica Holland, Lisa Evans, and industry stakeholders for their critical review of the draft documents; and the pollen producers, agritech companies, and Australian growers who were willing to be interviewed about artificial pollination.

Appendices

Appendix 1: Artificial pollination technologies: a review

Appendix 2: Business case for the supply of pollen to Australian horticulture

Confidential report for:

Hort Innovation
PH19004: The business of pollination in horticulture

PUBLICATION DATA

Broussard M, Martinsen P, Coates M, Dart K, Hoban S. February 2023. The business of pollination in horticulture. A Plant & Food Research report prepared for: Hort Innovation. Milestone No. 94894. Contract No. 40449. Job code: P/483000/01. PFR SPTS No. 23532.

KEYWORDS: Artificial pollination, mechanical pollination, pollination technology, hive insects, pollen donor farm.

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