Fruit fly research: Gap analysis

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Summary

Fruit flies are recognised as one of horticulture's most serious pests. A number of important species attack fruiting vegetables such as zucchini, capsicums, cucumber and eggplant. Restrictions on the use of chemical insecticides, particularly dimethoate and fenthion, have increased production issues and raised quarantine barriers in domestic and international markets.

The objective of this project has been to collate and review fruit fly research and development relevant to the vegetable industry. This information is evaluated and summarised in a categorised report appended to this document. Knowledge gaps and research needs have been identified in areas such as ecology and behaviour, pre-harvest management, postharvest controls and systems approaches.

Following discussion with growers and other industry members, the identified research needs were evaluated in terms of research cost, implementation cost, likelihood of success and potential industry benefits. Specific project concepts were prioritised and a five year plan is proposed.

The plan includes scope for basic research, on-farm trials and participatory research and implementation. Initial stages will examine specific treatments and aim to provide rapid results and "bang for buck". Following projects are more long term and strategic. The final stage is envisaged as a participatory research and implementation activity involving growers, grower organisations, researchers and government regulators, with a strong focus on communication and extension.

Identified research priorities with suggested start dates include:

- Effect of baiting perimeter plants (will be included in existing project)
- Exclusion netting and barriers (will be included in existing project)
- Use of buffer zones to protect vegetable crops (new, 2015)
- Effect of plastic mulch and subsurface irrigation on fly survival (new, 2015)
- Develop a commercially viable ICA based on greenhouse production (new, 2015)
- Optimise bait (+/-MAT) application for vegetables (2016)
- Effect of combining control methods – development of a systems approach (2016)
- Pilot AWM with grower clusters – implementation of a systems approach (2017)

It is further proposed that a structure be put in place to ensure regular (min 6 monthly) communication between researchers funded by HIA on fruit fly projects relating to vegetables. This will ensure that project activities are complementary, not overlapping, and achieve maximum industry benefits. Regular (annual) meetings with vegetable industry representatives by this group of project leaders should also be considered.

Keywords

Fruit fly, Bactrocera, Ceratitis, Dacus, Dirioxa

Ecology, Environment, Flight distance, Dispersal, Landform, Temperature, Host resistance

Pre-harvest control, Insecticide, Baits, Male annihilation, Mass trapping, Repellent, Barrier, Hygiene, Biological control, Sterile insect technique

Postharvest control, Probit, Disinfestation, Cold storage, Heat treatment, Fumigation, Irradiation

Systems approaches, Area wide management

Introduction

Fruit flies are recognised as one of the world's most serious pests for horticulture. They can breed rapidly, disperse widely and successfully attack most fruit and fruiting vegetables. Infested fruit are destroyed, while the larvae are a major quarantine issue for both domestic and international markets. Fruit flies are difficult to control with registered pesticides and can survive extremes of heat, cold, moisture and atmospheres that kill other pests.

Bactrocera tryoni – Queensland fruit fly (Qfly) – is the most important pest of fruit and fruiting vegetables produced on Australia's eastern and northern coasts. An Australian species, it affects both domestic and international trade. In 2000 Sutherst *et al.*[1] estimated annual economic losses at $28.5million, the result of both direct production loss, management costs and trade barriers. Losses are likely to be significantly greater now, especially given the recent loss of the fruit fly pesticides dimethoate and fenthion from most uses on vegetables.

As a result, an estimated $128 million was spent on fruit fly related activities between 2003-2008 (PHA, 2008). This included surveillance activities, control, postharvest treatments and research.

While the majority of this expenditure was on Qfly, other species are also significant. Western Australia is currently free of Qfly, however Medfly (*Ceratitus capitata*) is a barrier to domestic trade in vegetables to the east coast. Cucumber fly (*B. cucumis*) is an increasingly important pest of cucurbit species such as zucchini, pumpkins, cucumber and squash and can also infest other vegetables. Significant impacts on production have been reported in vegetable growing areas such as the Lockyer Valley. It also seems likely that some crop infestations blamed on Qfly are actually due to Jarvis fly (*B. jarvisi*) or Lesser Qld fruit fly (*B. neohumeralis*).

International trading partners, including New Zealand and China, are starting to question the control of other Australian species not previously considered to have economic or quarantine significance. As well as lesser Qfly and Jarvis fly, these include Island fly (*Dirioxa porna*), Northern Territory fruit fly (*B. aquilonis*) and Mango fruit fly (*B. frauenfeldi*).

Project VG12042 recognised that fruit flies are a major impediment to domestic and international trade in vegetables, particularly vegetables from Queensland. Improved data sets, lures and other methods of control were recommended as a high priority for continued investment.

Much has already been written on fruit fly control in Australia. A search of the literature reveals more than 300 papers on Qfly control alone. This is in addition to literally hundreds of project reports, agricultural bulletins, fact sheets and other materials that have been generated over more than 100 years of attempting to control this pest.

In 2009, the Fruit Fly Body of Knowledge (BoK) was created in recognition of the large and diverse literature and data generated on fruit flies in Australia. This resource includes "grey literature" – data generated but never published. While a recent project has categorised the literature within the BoK, accessibility is still extremely limited.

[1] Sutherst RW, Collyer BS, Yonow T. 2000. The vulnerability of Australian horticulture to the Queensland fruit fly *Bactrocera tryoni*, under climate change. Aust. J. Agric. Res. 51:467-480.

While aspects of Qfly control such as ecology[2] dispersal[3], parasitoids[4], chemical controls[5] and baits[6] have been reviewed, none have focused on the specific impact of fruit flies on vegetables, or compared the different methods that can be used to control them in the field and postharvest.

There remained a need to summarise, interpret and implement this information, particularly as it relates to the specific needs of the vegetable industry. This can then be used to focus new research efforts where they will have most benefit for the industry.

Information on fruit flies, as it relates to levy paying vegetable crops, is summarised in the separate document appended to this report. Each topic is headed by a paragraph summarising the main point of the topic as it relates to vegetables. Background information is then provided in greater detail in a following series of dot points. Research needs, if any, are included at the end of each section.

This report is focussed on knowledge gaps, research needs and a plan for investment by the Australian vegetable industry.

[2] Clarke AR, Powell KS, Weldon CW, Taylor PW. 2011. The ecology of *Bactrocera tryoni* (Diptera:Tephritidae): what do we know to assist pest management? Ann. Appl. Biol. 158:26-54.
[3] Dominiak BC. 2012. Review of dispersal, survival and establishment of *Bactrocera tryoni* (Diptera: Tephritidae) for quarantine purposes. Annals of Entomological Soc. Of America. 105:434-446.
[4] Zamek AL *et al*. 2012. Parasitoids of Queensland fruit fly *Bactrocera tryoni* in Australia and prospects for improved biological control. Insects 3:1056-1083.
[5] Dominiak BC, Ekman JH. 2013. The rise and demise of control options for fruit fly in Australia. Crop prot. 51:57-67.
[6] Barclay HJ, Hendrichs J. 2014. Models for assessing the male annihilation of *Bactrocera* spp. *w*ith methyl eugenol baits. Ann. Entomological Soc. Amer. 107:81-96.

Methodology

A thorough review of literature on fruit flies was undertaken. Sources of information included peer reviewed literature on endemic and exotic fruit fly species, conference proceedings, HAL Reports, CRC for Plant Biosecurity reports, information provided by the State agencies and personal communication from experts in specific areas such as baiting, sterile insect technique, and interstate regulation.

Research on fruit flies is summarised in the document appended to this report. Analysis of this document resulted in identification of knowledge gaps and research needs. These have been prioritised according to cost, likely success and potential commercial viability.

Growers and service providers were also surveyed to determine their level of interest in various fruit fly control strategies and options for future development.

Outputs

The major output from this project is the attached gap analysis document.

Results were presented at the November 2014 Bundaberg fruit and vegetable growers forum in Bundaberg.

Outcomes

Knowledge gaps identified

- How well does research on tree fruit transfer to vegetable crops?
- What are the special characteristics of vegetable crops that can be used within fruit fly systems approaches to improve control?
- What are the most effective ways to use existing control strategies including baits, MAT, cover sprays and lures to protect vegetable crops?
- Can barriers such as windbreaks, floating row covers and hail netting contribute to fruit fly control in vegetables, for both production and market access goals? What are the economics of these measures?
- What do we know about fruit fly species other than Qfly and Medfly that we can use to manage these potential pests?
- Can trapping data be related to actual field infestation levels in a meaningful way? If so, can this information be combined with host susceptibility data to re-define an area of 'low pest prevalence' with respect to fruiting vegetables?
- What is the potential for use of area wide management in major vegetable production areas such as Bundaberg and Bowen? Given that biological measures such as SIT are unlikely to be effective and Government support may be limited, could AWM still be implemented in certain farming clusters?
- How much do existing practices—harvest method, postharvest inspection, washing, packaging and storage—contribute to elimination of any infested products from the supply chain?
- Is there potential for acceptance of sub-probit 9 control measures eg short cold storage treatments, in combination with other mitigation strategies, as a protocol for market access for vegetables? In effect, is there potential for acceptance of systems approaches by target markets for vegetable crops?

Research needs

Any discussion of what is known and unknown about fruit fly can raise as many questions it answers. Certainly, to many growers, 'Research Needs' may appear to be only limited by the interests and imagination of researchers! Nevertheless, a number of key research questions can be identified from the attached review of fruit fly research. These include:

- Quantify the effect of creating a buffer zone on entry of flies into a vegetable crop to determine whether this would be a useful component of a systems approach.
- Examine temperature data for vegetable production areas to determine whether a winter window could be used more widely to access fruit fly sensitive markets.
- Test the ability of mature larvae to survive and pupate where vegetable crops are planted into plastic mulch and irrigated using subsurface drippers— hot dry conditions may reduce pupal survival.
- Test the effects of applying bait or insecticide to tall plants (such as forage sorghum) planted around vegetable crops. Research questions include the relative attractiveness of different plant species, the spacing needed around and within a crop and whether both male and female flies roost in such crops.
- Quantify relative resistance of different vegetable crops to infestation by fruit fly while attached to the plant (as opposed to detached fruit in the laboratory) in order to develop a host susceptibility index similar to the scale developed for citrus[7].
- Monitor movement of female flies into a vegetable crop from perimeter areas using food based traps and determine the relationship between such trap catches and fruit infestation (previous research found little or no relationship between parapheromone trap catches and vegetable infestation).
- Field trials to evaluate the efficacy of new or existing insecticides against fruit fly in vegetable crops. These will help determine whether registration for this use is warranted.
- Optimise bait application method and timing for use in vegetable crops. This should include differences in effectiveness when bait is sprayed on foliage compared to in a bait station or on perimeter crops, optimum bait height for different species and use of thickeners. Previous research on bait application in orchards may be of little relevance to vegetable crops.
- Determine how MAT can be best incorporated in a vegetable crop. For example, should blocks be placed only around the perimeter of the crop or should they be installed at intervals within the crop as well.
- Determine whether repellents such as kaolin or oils can protect vegetables from fruit fly infestation. Any study should include analysis of the effects of such repellents on productivity and marketability of the crop.

[7] Lloyd AC et al. 2013. Host susceptibility of citrus cultivars to Queensland fruit fly (Diptera:Tephritidae). J. Econ. Entomology. 106:883-890.

- Trials are needed to test the use of different types of exclusion netting on and around vegetable crops. These include visual barriers and floating row covers. Tests can determine optimal materials (mesh size, weight, light transmission) and application method (draped directly over crop, suspended on hoops, as a perimeter fence) for different vegetable crops. Studies should include effects on water use efficiency, other pests, diseases and physiological disorders such as sunburn and blossom end rot, providing a cost:benefit of such protection.

- Data is needed to support an ICA based on greenhouse production plus inspection. This could include monitoring inside the greenhouse and postharvest inspection.

- Field sanitation is often suggested as a means of fruit fly management but the effects in vegetable crops have not been quantified. Any study should include hosts of both *B. cucumis* and Qfly and consider both the costs and benefits of destroying discarded/dropped fruit during and after crop cycles.

- Trials are needed comparing cold tolerance of different fruit flies of quarantine concern in vegetable crops. This could be combined with existing data on cold treatment of Qfly in capsicums to formulate a quarantine protocol for export markets.

- The effect of combining different components of a systems approach on the probability of infestation, such as that described in the Beyond Compliance model, needs to be ground truthed. While such models can provide guidance on where to allocate resources and the number of measures required, they are unlikely to be adopted without supporting data.

- While no vegetable production areas are currently operating area wide management (AWM) for fruit flies, potential exists for implementing pilot schemes on a cluster-based approach. Research could optimise the operation of an AWM cluster and provide the data and cost benefit analysis to support wider adoption.

Industry priorities

A total of 34 industry representatives were asked a few short questions about priorities for future fruit fly research. These were presented as multiple choice questions and followed presentation and discussion of the information in the attached report.

The participants comprised:

Grower	32%
Agribusiness / advisory	25%
Industry organisation	18%
Researcher / Government / other	25%

Q1 Do fruit flies affect production on your / your clients' farms?

Clearly this question was not applicable to a significant number of the participants. However, 80% of those to which it did apply replied 'YES', with only 7% agreeing with the statement 'No, because dimethoate is still available' and the remainder stating that other crop protection methods (protected cropping, other cover sprays etc.) were effective at controlling fruit fly.

Q2 Do fruit flies affect access for your / your clients' product into fruit fly free markets (NZ, Tasmania)?

Again, this was not relevant to government representatives and researchers. However, a clear majority of the remaining participants (70%) agreed that they had lost business since the changes in chemical registrations.

Q3 What do you think is the future for dimethoate use?

This question provoked a mixed response. As shown below, there is a high degree of uncertainty about the future of this (and presumably other) chemical insecticides. However, it was clear that **none** of the respondents anticipated that dimethoate use would continue in the long term.

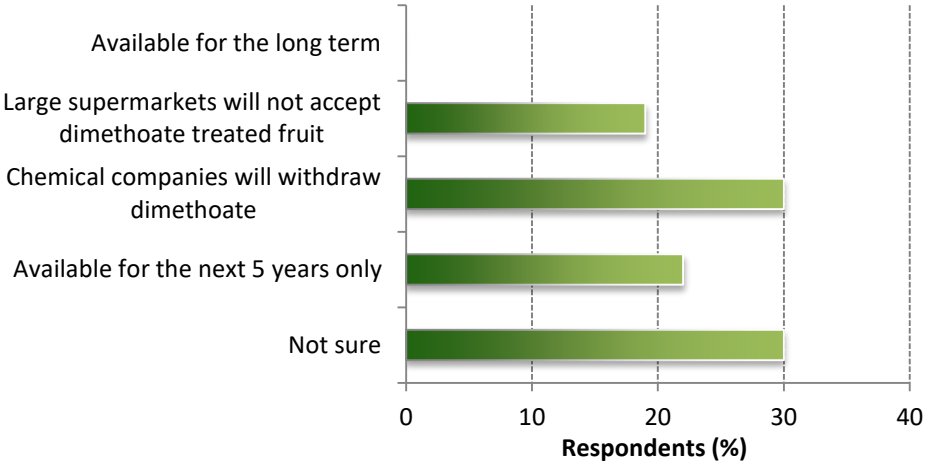

Figure 1 – What do you think is the future for dimethoate use?

Q4 How do you think you will be controlling fruit fly in ten years time?

While a small percentage of participants stated that they had 'no idea', the majority (83%) thought that they would most likely be using a systems approach, combining strategies such as baits, traps and MAT. Only a small number thought they would be relying on other insecticides (4%) and no-one selected the dimethoate option.

Q6 If we were to set up a fruit fly management trial in the region, you would be most interested in (choose up to three in order of priority)

While it is possible that the results were affected by the order of possible responses, the results appear to demonstrate clear support for the first two strategies; protein baiting + MAT and physical barriers.

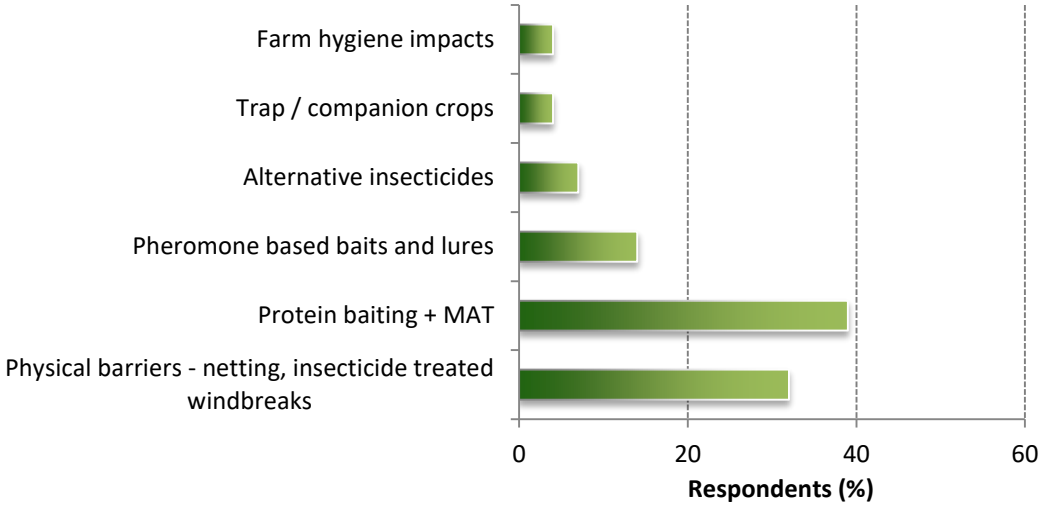

Figure 2 – What sort of fruit fly management trial would be most interesting to you?

Q7 Who would need to be primarily responsible for driving Area Wide Management in your Region?

It had been expected that many of the participants would see implementation of any AWM of fruit fly as a government responsibility. However, these participants clearly saw that success requires active participation from growers themselves, perhaps with support from regional organisations. The role of government in AWM is unclear—although only 4% selected this option, it seems unlikely that any AWM program could be effective without government support, at least in the initial stages.

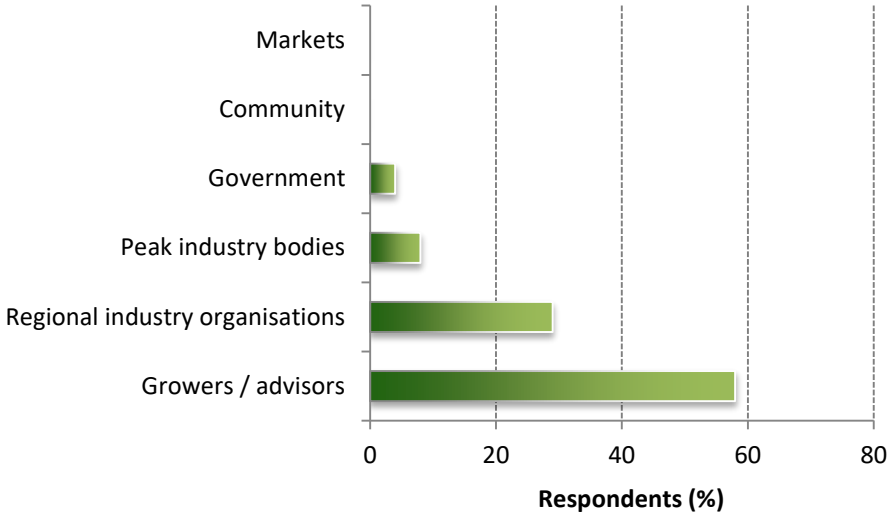

Figure 3 – Who is responsible for AWM?

General discussions with industry members suggest many are dissatisfied with much of the research that has been done in the past. There is a perception that a lot of money has been spent with little or no industry outcomes. Many feel that researchers are more concerned with publishing papers and gaining prestige with their employers and peers than in practical outcomes for farmers.

In addition, while fruit fly is a significant production problem, there is a feeling among some growers that other significant issues—such as thrips and whitefly—deserve more attention:

> *'Haven't we **done** fruit fly? We've got lots of other pests you can work on too you know…'*

Market access is a further source of frustration. One large and progressive grower who has already replaced insecticides with baiting, hygiene and MAT on his farm is now finding himself forced back into (probably unnecessary) calendar based cover sprays in order to meet interstate ICA requirements. Conflicting messages from different government authorities certainly do not help growers to change.

Moreover, the lengthy negotiations and lack of clarity in requirements that are typical of market access negotiations, whether international or interstate, create their own frustrations:

> *'It doesn't matter how much information we give (them), and how much we talk about it, and how good it is, in the end this official just turned round and said 'but where's your killing treatment?'. And that was the end of it.'*

Research needs to be relevant to industry needs, commercially viable to use and acceptable to regulators. For this to occur there needs to be clear communication between growers, researchers and regulators. While certainly not easy, this is essential if research is to find practical application.

Recommendations

Research priorities

The various identified research needs have been considered in terms of:

- Estimated cost of the research,
- Likely cost to implement on farm,
- Probability of the specific research project succeeding in its objectives and
- Potential benefits to industry if the project succeeds.

It is acknowledged that this necessarily simplifies some of the issues, especially when considering market access priorities. For example, although "winter windows" have generally had limited success, if a winter window can be used to access a specific and lucrative market then benefits may be considerable. Also, if market access is a priority over production, the relatively high research costs and risk of a project developing a postharvest treatment may be well justified. There is also value in having a range of market access options, enabling growers to respond quickly to changing market conditions.

In addition, although the four factors are assessed equally, a project that fails to meet the final criteria of at least 'good' benefits to industry should clearly not be a priority. As may be seen on the table overleaf, although the 'effect of existing postharvest practices on larval survival' project scores well overall, the chance of acceptance by regulatory authorities is unknown. It is proposed that this (and possibly the greenhouse ICA project, although this has a better chance of acceptance) should only be funded if it can be demonstrated that there is a reasonable likelihood of acceptance of the results under an interstate ICA and/or international agreement.

The two highest priorities for in-field control research are the use of perimeter baiting and exclusion netting. Exclusion of flies from a production area by physical or chemical means is certainly the best strategy in fruit fly management. If successfully applied, they avoid any need to treat the products in-field or add damaging and costly postharvest treatments. As such measures effectively produce a pest free place of production (PFPP) they are also likely to be accepted for domestic market access.

These priorities have become clear over the course of this project and have been adopted by current projects VG13041 and VG13042. Exclusion and perimeter baiting treatments are therefore already included in the 2015 trial program. Should positive results be obtained it may be possible to build on these projects further.

Analysis of Research project needs.

KEY:	COST	PROBABILITY OF SUCCESS	POTENTIAL BENEFIT	POINTS
	inexpensive	likely to succeed	excellent	4 points
	moderate	probably will	good	3 points
	significant	possibly could	some potential	2 points
	very expensive	a long shot	doubtful or unknown	1 point

Research need identified	Research cost	Cost to apply	Probability of success	Potential benefit	Total Points (max = 16)
Ecology and Environment					
Use of buffer zones to protect crops		*variable*			**12**
Temperature data for winter windows					**10**
Effect of plastic mulch on survival					**13**
Varietal resistance to oviposition					**6**
Monitor female dispersal into crop with food based lures					**11**
Pre-harvest controls					
Optimise use of MAT in veg crops					**10**
Optimise bait application method					**11**
Effect of baiting perimeter plants					**12**
Efficacy of new insecticides					**8**
Repellents eg kaolin, oil					**7**
Exclusion netting					**12**
ICA based on greenhouse production					**12**
Effectiveness of field hygiene					**10**
Postharvest controls					
Comparison of species cold tolerance					**9**
Effect of existing postharvest practices					**11**
Systems approaches					
Effect of combining control methods – development of a systems approach					**12**
Pilot AWM with grower cluster					**11**

Research timeline

Based on the analysis of research needs, the following projects are proposed for funding by the Australian vegetable industry over the next five years:

KEY

- Existing projects
- New project for tendering in 2015
- New project proposed to commence 2016
- New project proposed to commence 2017

	2015	2016	2017	2018	2019
Use of buffer zones to protect vegetable crops					
Effect of plastic mulch and subsurface irrigation on fly survival					
Effect of baiting perimeter plants (VG13041 will include this treatment)	Potential to extend based on results of VG13041				
Exclusion netting (VG13042 will include trials)	Potential to extend based on results of VG13042				
Optimise bait (+/-MAT) application for vegetables					
Develop a commercially viable ICA based on greenhouse production					
Effect of existing postharvest practices on larval survival	TBD				
New postharvest treatments including novel fumigants and low dose MB	(VG13043 and VG13044)				
Effect of combining control methods – development of a systems approach					
Pilot AWM with grower clusters – implementation of a systems approach					

This plan has a number of key components, which should ensure results from the program are optimised.

- Existing projects will address the two main priorities for in-field management research: perimeter baiting and exclusion netting. Trials are already underway with initial results likely to be available before June 2015.
- New projects for 2015 on buffer zones and plastic mulch are focused on using existing grower practices to help control fruit flies, thereby producing fast "bang for buck" production benefits

from research funding.

- An additional new project developing a commercially viable ICA based on greenhouse production should also be able to produce tangible results (ie domestic market access) relatively quickly (approx. two years).
- Projects proposed for 2016 are larger and more complex but will build on the initial, smaller scale trials on specific treatments.
- Optimising bait and MAT use for vegetables will add value to earlier research on perimeter baiting. It will also make this method available for growers for whom shelterbelts are not an option.
- It is expected that the first year of the project "development of a systems approach" would be spent verifying the additional effects of specific control strategies (as per the "Beyond compliance" model). The other two years would be focused on semi-commercial implementation and assessment of these practices.
- The final project conducting a pilot AWM with grower clusters would naturally flow from the systems approach project and work closely with it. This project would be developed as a participatory research activity with a strong focus on extension and communication. The research team should include growers, grower organisations, researchers / advisory and government regulators for maximum impact.

One of the key concerns expressed by industry with regard to past research is that activities have been repeated unnecessarily, or that different projects overlap, 're-inventing the wheel' at industry expense. Some research projects are perceived as developing solutions that are not commercially viable, or failing to clearly communicate the results to potential users.

To avoid these issues, it is proposed that a structure be put in place to ensure regular (min 6 monthly) communication between researchers funded by HIA on fruit fly projects relating to vegetables. This will ensure that project activities are complementary, not overlapping, and achieve maximum industry benefits. A regular (annual) meeting with vegetable industry representatives by this group of project leaders should also be considered. This will help inform all stakeholders of research objectives and progress, avoiding duplication and ensuring trials focus on cost effective solutions. A small budget (approx $3,000 annually) invested in such an activity could potentially prevent much greater waste.

Intellectual Property/Commercialisation

No commercial IP generated

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Many in Government, Research and Industry have provided comments, feedback and additional information during this project.

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Appendices

Report attached as a separate document.