Crossing the Valley of Death: different perspectives on main-streaming *Eretmocerus hayati* into vegetable IPM systems

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Abstract. Since its detection in Australia in 1994, silverleaf whitefly, *Bemisia tabaci* biotype B, has impacted on Australian vegetable production by reducing yields, product quality and vectoring viruses. At times, spray failures due to insecticide resistance and poor spray coverage made the pest unmanageable. To develop workable IPM strategies for the pest, the parasitoid *Eretmocerus hayati* was imported into Australia by CSIRO in 2002. Over the next decade, this parasitic wasp was integrated into North Queensland's vegetable farming systems by DAF staff and others through an extensive program of research station trials and on-farm work with growers. It is now commercially available through Bugs for Bugs. This paper explores the wasp's journey from immigrant to main-stream IPM strategy by gathering perspectives from key people involved in the *E. hayati* 'innovation' process. Responses provide insights on the challenges experienced along the way and highlight factors critical to successfully integrating biological control agents into complex IPM systems.

Keywords: biological control, IPM implementation, silverleaf whitefly

Introduction: the silverleaf whitefly problem

The detection of the exotic pest silverleaf whitefly (*Bemisia tabaci* biotype B) in Australia in late 1994 was first reported by Gunning et al. (1995). Based on experiences with silverleaf whitefly (SLW) incursions elsewhere, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) considered the pest a substantial threat to Australian agriculture and in response put together a 10 year SLW research and development proposal for industry to consider.

In vegetables, SLW was first found in North Queensland during the 1996/1997 summer. First outbreaks occurred in Bowen during the 1997 and 1998 seasons with tomato and cucurbit crops worst affected. Existing insecticides provided a temporary fix, however spray failures due to insecticide resistance and poor spray application meant that growers still experienced 50-60% crop damage in the seasons that followed. By 2005, SLW damage had stabilised as permits for new 'soft' chemistry had become available for vegetables.

Plant response to SLW infestation varies, with a wide range of vegetable crops affected. Some crops are more sensitive than others. The pest impacts on crops through feeding, plant reaction to a toxin injected during feeding, secretion of honeydew leading to sooty mould and vectoring of viruses. The exotic Tomato Yellow Leaf Curl Virus was detected in Australia in 2006 (Van Brunschot et al. 2010) and this added fresh urgency to effective SLW management.

In this paper we trace the history of how the parasitic wasp *Eretmocerus hayat*i (called *hayati* in this paper) was integrated into silverleaf whitefly management strategies over the past 20 years. The recollections of people closely involved in its journey from imported biological control agent to commercially available parasitoid are reported. The focus is the major vegetable growing areas of Bowen and the Burdekin in North Queensland where targeted releases of *hayati* are most widely used to manage SLW.

Gathering different perspectives

In April 2017, the lead author interviewed eight key people directly involved in solving the SLW management problem and/or getting *hayati* to market. After making initial contact, each person was sent a copy of the abstract, and then interviewed several days later using a set of open-ended questions to guide the conversation. All were happy to contribute, keen to see the results and most requested a copy of the paper. The question set explored:

- the person's involvement in SLW and *hayati* work
- fit of *hayati* within vegetable IPM systems - current use, effectiveness, how to increase use
- steps to commercialising *hayati* – critical factors, barriers, what could have been done better, threats to its continued availability and use
- vegetable IPM in the future with opportunity to make further comment.

Commonalities and insights emerged quite quickly with each respondent providing their own unique perspective of the SLW problem and *hayati*'s role in its solution. Over the following four months, the lead author clarified some specific events and activities with three of the initial respondents, cross-checked information with that in published papers and final project reports and interviewed a further five people to round out perspectives.

Developing the Integrated Pest Management (IPM) system

Within two years of SLW's detection in Australia, CSIRO started out on a 10 year SLW research program by securing funding from various industry and government sources including the Australian Nursery Association, Australian Vegetable Industry (AusVeg vegetable levy), Horticulture Research and Development Corporation (now Hort Innovation), Queensland Fruit and Vegetable Growers (now Growcom) and Cotton Research and Development Corporation. The phases of this included:

- *1996-1998* SLW biology, taxonomy, ecology, distribution and parasitism levels (with Department of Agriculture and Fisheries (DAF) input).
- *1999-2002* SLW IPM, geminiviruses, natural enemies including endemic and exotic parasitoids, 'soft' pesticides, rationale for importing *hayati*. A DAF entomologist was appointed to the Bowen Research Station in January 2000 to assist with CSIRO's research program on insecticides, SLW biology, thresholds and monitoring. The *hayati* import decision was made in 2001, with the wasp placed into quarantine in spring 2002.
- *2003-2005* parasitoids, insecticides, area-wide resistance management, grower information and extension. From October 2004 to May 2005, approximately 617,000 *hayati* were released at various sites across Queensland and their establishment evaluated (De Barro et al. 2006). In addition, a CSIRO/DAF third party project with co-investment from Sumitomo Chemicals as well as a DAF fee-for-service project with Bayer Crop Sciences accelerated the availability of new selective (soft) insecticides to the vegetable industry.

Integrating hayati into the IPM system

Over the next decade, the priorities of the CSIRO and DAF efforts diverged. While the goal for both was effective SLW management within an integrated approach, CSIRO tended to focus at the landscape level while DAF's focus tended towards the farm scale. It is a subtle difference that impacted on how *hayati* was integrated into SLW management. CSIRO's objective was to establish (and protect) *hayati* in the environment. DAF's aim was to develop IPM systems that included targeted *hayati* releases as a strategy to manage SLW in crops and to augment background populations.

From October 2005, CSIRO continued *hayati* release, post-release evaluation and habitat management work. By March 2008, CSIRO had released over 1 million *hayati* into the Australian environment since their initial October 2004 releases (De Barro & Coombs 2009). Subsequent research investigated strategies for maximising *hayati*'s impact on SLW populations and disseminating this information to growers and industry (De Barro & Schellhorne 2012).

From 2006 to 2010, DAF continued IPM systems development through research station and on-farm trials: biological control, new chemistry integration, insecticide resistance testing, regional resistance management strategies, engaging growers and industry (consultants, agronomists and agricultural suppliers), SLW threshold levels, crop monitoring and weed studies. The local DAF entomology team also established a *hayati* rearing facility at Bowen Research Station using field collected strains from the Lockyer Valley. The first release was made in a Bowen cucumber crop in October 2006. Over the next two years (to December 2008), 1.3 million *hayati* were released on 30 collaborating vegetable farms in the Bowen and Burdekin regions and their impact on crops and non-crop areas evaluated (Sivasubramaniam & Subramaniam, 2015).

Awareness of and demand for the wasp increased. Over the 2011 to 2013 'transition period', DAF continued rearing *hayati* for targeted releases to further test and refine *hayati* use within the on-farm SLW IPM system. This work was largely financed by a commercial-in-confidence project using co-investment from a large grower to leverage DAF resources.

Commercialising hayati

Bugs for Bugs is a national biocontrol agent supplier that grew its business from its involvement in citrus IPM. The company has been in business for more than three decades. While aware of CSIRO's plans to import and release *hayati* early on and interested in its potential as a biocontrol agent, the company declined a 2006 request by DAF to supply *hayati* for farm trials and evaluation. The decision to commercialise *hayati* was not made until 'proof of concept' for rearing the wasp as well as the targeted release approach was available. This was achieved through intensive on-farm testing of the SLW IPM approach and *hayati*'s role within that management system by the Bowen DAF team. A prepayment from a large grower to show commitment also helped to convince Bugs for Bugs that there was enough industry support to proceed with the new business venture. As the director of Bugs for Bugs said:

> Biologicals are not easy to produce, some are impossible as not all lend themselves to mass rearing. Some are very fragile. A lot of the work had already been done. It still took a long time to commercialise - up to five years and a significant investment from us.

Start-up was in 2013, first commercial supplies in 2014 and full production in the 2015 season with the Bowen DAF team continuing to provide information, advice and expertise to the supplier, growers and consultants. It took two years to bulk up supplies and DAF had to re-supply once from a small colony kept for experiments (and as back-up) as the commercial colony collapsed in 2016. From 2014 to 2017, this local DAF support ran on a very lean budget as part of a larger virus focused area-wide management project led by DAF virology in Brisbane.

Market penetration – hayati as a mainstream IPM strategy

Fit into IPM system The wasp is robust, fecund, very effective, disperses well and is well-suited to the climate of Queensland's Dry Tropics (respondents, De Barro & Coombs 2009). Those with hands-on day-to-day experience in managing pests within complex vegetable production systems were positive about *hayati*'s fit within IPM. It is seen as an important tool for keeping SLW in check, with the impact of the 2016 *hayati* supply problem illustrating the point: 'Where are my bugs? How can I manage pests without them?' as one grower said to his consultant.

Use Use of *hayati* is widespread in the Dry Tropics with 80% of sales going into the region and respondents estimating that targeted *hayati* releases are used as part of an IPM system in more than 50% of vegetable crops in the Bowen and Burdekin areas (90% of Bowen tomato crops). Remaining sales were going into the Lockyer and Fassifern Valleys in South East Queensland (tomato, green beans) and there was some interest in NSW (cotton).

Effectiveness Release timing and numbers, regular monitoring, use of 'soft' chemistry as well as how to best preserve background populations over non-crop periods are important for getting the most out of *hayati*. Good technical information on *hayati* use is only available for melons but is needed in particular for SLW-sensitive crops such as tomato, pumpkin, and zucchini. While seen as reasonably effective, detailed research to obtain specific technical data on *hayati* releases in these other crops would improve its use. Regular monitoring of parasitism levels is an extra cost and so can be can be difficult to achieve for consultants/agronomists. More 'soft' chemical options for all pests would help protect *hayati*.

Expanding the market The majority of respondents saw targeted releases as the more critical. Background populations were seen as useful within an area-wide management context. Early season releases while SLW populations were low, releases in non-crop areas (riverbanks, bushland) and vegetation management to preserve *hayati* from season to season point to a move towards converging with the ecologically based CSIRO landscape design approach. Market access issues, the need to keep farms clean and clear of weeds (disease, hygiene, other farm operations), SLW's threat as a virus vector and the need to manage a range of other pests complicates matters.

Some suggestions for expanding *hayati* use include talking with non-users to explain benefits, keeping *hayati* in people's minds when SLW is not a problem, making *hayati* easier (and more cost effective) to release, for example through drones, better pricing and another supplier (more competition).

Targeted releases of *hayati* as a biological innovation

As a quick Google search reveals, there are numerous innovation models and theories and thoughts on the difficulties of taking an innovation from concept through to commercialisation. The discussions have a similar feel to the soul searching that is often done around how to get farmers to adopt new technology and research outputs in order to improve their practices, processes and systems.

Concepts that apply include the difference between invention (discovery, basic science) and innovation (many definitions - new idea, device, method, process, solution – something original and more effective), the S curve of technology adoption over time first plotted by Tarde (1903), the Diffusion of Innovations theory first proposed by Rogers (1962), and the insight of Schumpeter (1942) of innovation as waves of 'creative destruction' in the marketplace, which is again gaining currency in today's thinking about innovation.

Despite its shortcomings, the Linear Innovation Model reviewed by Godin (2006) remains in use partly because of its simplicity but also because it allows measuring/evaluating of alternatives. In its simplest form, its steps are Basic research → Applied research → Development → (Production and) Diffusion. It has similarities with the Transfer of Technology model used in agricultural research, development and extension. Variations of the linear model include:

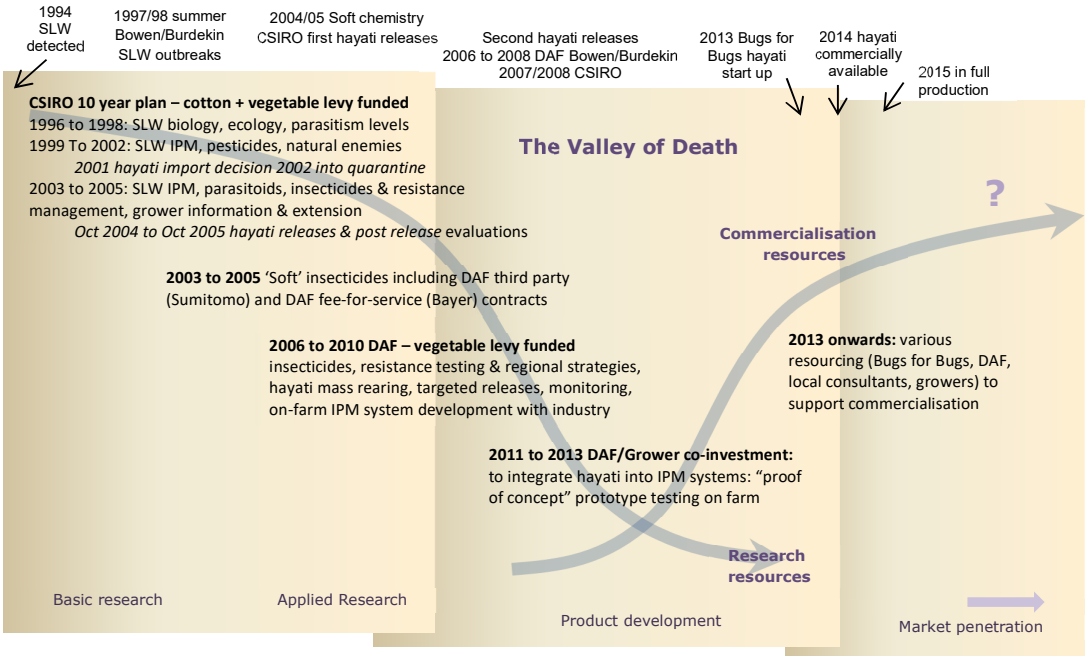
- Technology push where marketing and sales are added after production.

- Market pull where research and development respond to a market need – such as finding an effective way of managing SLW.
- The phase gate model which recognises that there are feedback loops and time variations between steps and uses readiness criteria to move between major phases of innovation – SLW IPM system development and *hayati* commercialisation certainly contained feedback loops, time variations between steps and elements which had to be in place before moving to the next phase of innovation.

Bridging the Valley of Death

The diagram in Figure 1 attempts to overlay a simplified innovation model (adapted from Dacey 2014) with the key events and stages of SLW IPM system development and *hayati* commercialisation. The research and commercialisation resource input lines represent the investment trend, not actual dollar values.

Figure 1. Getting *hayati* across the "Valley of Death"



The exact positioning of different phases/projects against key events could be argued. For simplicity, the model also contains no feedback loops (which were extensive) and only weakly indicates the high degree of overlap between different stages. By mapping events against this simplified model what does become clear, however, is that the intensive on-farm 'prototype' testing work by DAF in collaboration with a large grower was the springboard that took *hayati* across the Valley of Death and into commercial supply. This conclusion is borne out by interview responses. Figure 1 also indicates that resources were then at their lowest ebb with this 'transition period' financed by a large grower to leverage State (DAF) funding through a commercial-in-confidence project.

<u>*What was critical for commercialisation?*</u> There are some obvious steps that were vital for making supply and targeted release of the biological innovation *hayati* (i) possible and (ii) a commercial proposition:

- Identification of the most suitable species, getting it through importation and quarantine requirements, developing the initial breeding, release and evaluation methods and documenting this knowledge.
- Generating the basic data on SLW biology and ecology within the Australian environment on which effective management strategies for the pest could be built.
- Integrating SLW management strategies into an IPM system suitable for *hayati* releases especially the 'soft' chemistry innovations

- Generating knowledge about *hayati* use – targeted release timing to augment background populations, numbers to release, how to assess effectiveness, SLW and parasitism monitoring, threshold levels, pesticide selection and so on.

It needed people with a holistic view to drive the 'proof of concept' work and make it into a business opportunity with enough market demand to make it feasible. It represents a 20 year investment in time, money and effort, from CSIRO's exploratory research starting in 1995 through to the IPM system development and prototype testing by DAF over more than a decade resulting in the first commercial *hayati* supplies in 2014.

It involved building up grower and industry confidence through one-on-one collaborations, building relationships and trust and providing ready access to problem solving expertise and advice. It also required expertise for mass rearing methods that could deliver a consistent, quality supply of *hayati* in the numbers needed as the growing season progressed. 'Lots of research done to prove not only that it works but at what level; release rates, how many & when; balance cost with effectiveness' (consultant).

The high price of new chemistry helps to make *hayati* a viable option, as does SLW's ability to quickly develop insecticide resistance. Chemical companies are keen to extend the useful life of their new products within an integrated management approach that includes *hayati*.

Barriers Mass production of *hayati* for commercial supply is a complex breeding process that needs supply of live plants. The company had no experience in growing live plants. As the supplier said:

> Only one thing needs to go wrong and the whole thing falls down like a stack of cards – needs a back-up system and now employing someone else to look after an independent colony.

The extensive lead up work done by CSIRO and DAF, positive overseas information, the DAF back-up colony, and availability of support and advice helped to overcome this barrier. To spread risks, the business was established as a joint venture. To ensure a future market it needed a mind shift in thinking from growers and industry about targeted *hayati* releases and the softer IPM approach. The DAF on-farm demonstrations in the region were crucial in convincing enough people in the industry that *hayati* was a value proposition for managing SLW. People needed to feel comfortable that it would work. As one consultant said:

> Have to have faith. Sprinkling vials of wasps out over crops is a bit like witchcraft! I often look at fruit coming into the pack house late in the season. Cost is not a barrier if there is a result: cleaner fruit, less chemicals, better for consumers and the environment.

Another respondent wondered: 'Maybe Admiral [insecticide], which is not a knockdown and needs several days before impact is observed vs the traditional sprays where impact is more immediate, set a precedent. It's a leap of faith'.

What could have been done better? Most respondents thought that better collaboration, more open communication, greater sharing of information and resources could have sped up the research and made *hayati* use more widespread by overcoming entrenched thinking. There was acknowledgment that competition for resources and commercial realities made this difficult and that only one-on-one on-farm trial work under commercial conditions could build the confidence needed for this new approach.

Threats to continued hayati supply and use The general consensus was that having only one *hayati* supplier was a problem both from a supply assurance and price perspective. DAF continues to keep a back-up colony and Bugs for Bugs is now producing *hayati* in two separate locations. The lack of IPM compatible insecticides especially for managing other pests (bugs, aphids, crickets, thrips, heliothis) and tighter market access restrictions (nil or low insect tolerance) can impact on market demand for *hayati*. In some ways, *hayati* has been substituted for increasingly expensive insecticides. A price drop in existing or new chemistry for SLW and other pests may again make insecticides the cheaper (and simpler) option.

Changes in farming generally, for example, increased corporate farming could mean large cropping areas are affected if the farm's decision makers see little value in *hayati* releases. And how might climate change and hotter seasons affect SLW and *hayati* populations?

What made the difference?

Exploring the process of integrating *hayati* into vegetable IPM systems with key people along the innovation pathway provided some great insights on what was critical for successfully commercialising an exotic biocontrol agent to manage an exotic pest problem. It confirmed current 'innovation theories' and what many of us know already: how long and difficult is the road from idea to full commercialisation. It highlights the critical role of one-on-one development work on-farm over time with growers, agronomists and consultants – the eventual end users of the

innovation – to demonstrate that the 'prototype' works and is a commercially viable proposition. For targeted releases of *hayati*, this was the bridge that spanned the Valley of Death.

Initial long-term approach CSIRO's strategic outlook and industry's foresight and willingness to invest in a ten-year program to combat an emerging exotic pest issue not only brought *hayati* into Australia, it provided the fundamental research on which SLW IPM strategies and *hayati* rearing, release and evaluation methods were developed for Australian conditions. In the current funding environment, with its focus on applied research and short-term returns, are industry and government willing to resource such long-term programs?

There was a crisis SLW's ability to quickly develop insecticide resistance challenged industry's more traditional approach to managing pests. Business as usual was not an option and, even once SLW outbreaks had stabilised, different sectors of the industry – growers, consultants, chemical suppliers – were keen to protect new chemistry through a more integrated approach to managing pests.

Persistence There was industry consensus that the groundwork driven by the local DAF team to demonstrate that 'it works' as well as early involvement of consultants expanded IPM implementation and *hayati* use and that this 'led to a critical mass of users'. Industry respondents expressed their appreciation of the research effort: 'want to thank the CSIRO and DAF teams who developed the methodology' and '(the DAF entomologist) should take a lot of the glory - he did the hard stuff and should be highly commended'.

Taking a risk Credit was given to growers who took the risk to try something different, in particular the grower who had collaborated with the DAF team to develop a better approach to managing SLW. Not only was he willing to trial targeted *hayati* releases as part of his crop management, he provided significant funding to help finance its commercialisation.

Participation and collaboration While communication came up as something that could have been done better, there was still a great deal of information sharing with individuals working together towards a common goal. There was a certain sense of pride in what had been achieved that came through during interviews.

Not only one innovation While this paper set out to better understand commercialisation of a biological innovation – the targeted release of the parasitoid *hayati* - other innovations are also in play. They include 'soft' chemistry that is IPM compatible and the integration of various pest management strategies within a system that delivers results under commercial conditions.

People continuity and locally available expertise Over the past decade or more, there has been little change in the key people driving the work in the Bowen and Burdekin regions. Since his appointment in 2000, the DAF entomologist and his team have developed close ties with the local farming community. The two well established consultants have operated in the district for many years, had previous experience with softer IPM approaches and biocontrol agents and employed local people as their support staff when they could. Several chemical company and agricultural distributor staff contributed to the resistance management effort over a number of years. Some are still working in the region's agricultural industries.

This meant that individuals were able to forge strong relationships and build trust within the industry. Experience and networks continued to expand and support, advice and problem-solving expertise was available locally - all factors conducive to building confidence in trying out a new approach. Will the technology survive if it is no longer driven by the current people?

A new generation of growers There has been a huge change in the vegetable industry over the past ten years. The next generation of growers has taken control; many are well educated, technology savvy and employ professional consultants and agronomists to help run their operations. They are hungry for new tools and ideas, environmentally aware and are willing to invest in their business. According to one consultant 'there has been a complete change in mindset at all parts of the chain'.

Silver bullets Has a point of no return been reached? If new, cheaper chemistry came along would industry revert to this less complex but probably short-term option? The response to the 2016 *hayati* supply problem would suggest that a number of growers no longer look for simple solutions to complex problems. There was also little evidence that some have relapsed to chemicals as their main strategy in the 2017 season, with the supplier getting more enquiries and positive feedback about beneficials from growers and industry.

Serendipity There were some happy circumstances at work. In the early 2000s, when the *hayati* import decision was being made, the researcher leading the US Department of Agriculture work was at that time with CSIRO in Brisbane. Two global chemical companies were willing to invest in

IPM strategies to delay SLW resistance to their new selective 'soft' insecticides which came on line around that time. A well-established biocontrol supply business was located in Queensland and successful prototype testing of *hayati* coincided with a drop in demand for parasitoids from the citrus industry due to new chemicals coming onto that market. The company was interested in new business opportunities.

Opportunities There was generally a positive view of where industry is heading and that industry and growers have changed the way they think about pests.

> It (*hayati*) needs to be part of a whole program – never see the main benefits until there is a system approach' (grower) and 'need to have a system based e.g. tomato IPM, rather than pest based e.g. SLW IPM, approach' (DAF entomologist).

Has the mindset shifted in enough people with SLW now in decline and less of an issue within manageable IPM systems? Respondents saw opportunities to develop and commercialise native species for different regions, replacing broad spectrum pesticides with other soft options including bio-control, and better co-operation between growers and others, although competition remains with people 'not wanting to divulge trade secrets' (consultant). The technologies and systems continue to evolve. Area-wide management and landscape design approaches were seen as something for the future. It is a good news story.

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