# Integrated Pest Management (IPM) Strategies for Greenhouse Hydroponic Production of Berry Crops

**A report for**

**By Wade Mann**

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# Executive Summary

The berry industry in Australia is currently experiencing significant growth under greenhouse hydroponic production systems. Growers of the main berry types (strawberries, raspberries, blackberries and blueberries) have attempted to modify the growing environment through the investment of protective cropping structures and systems to achieve increased yields and quality of berry fruit. In a controlled environment, it is also possible to target production windows not possible through conventional outdoor, soil-based berry cultivation.

The manipulation of, and adjustment in, climatic conditions within a greenhouse production system has provided consistency and stability for berry crop growth and development. Inadvertently, this has created a suitable environment for pest and disease establishment and infestation. An increase in supermarket demands for minimum quality standards regarding berry fruit presentation, durability and maximum residue levels has created further pressure on growers. Coupled with the lack in options for chemical control products it would appear that the adoption of Integrated Pest Management (IPM) strategies would be beneficial.

IPM is a common sense, proactive approach to crop protection demanding attention to monitoring and scouting; identification of the pathogen; recording of data and forecasting to determine economic thresholds. An informed decision can then be made on time of intervention and methods of crop protection control.

A range of controls including physical, cultural and biological based options should be considered before reverting to chemical controls, where possible. Within the biological based options, there are a number of arthropod biological control agents including predators and parasitoids, as well as entomopathogenic nematodes. Each of these beneficials are either host-specific or generalist in their pest targets, but performance maybe adversely impacted by climate conditions, day length and population levels.

Additionally, there are biological chemicals which are either specifically orientated towards disease control or insect pest control. These biological chemicals fall into a number of different groups, with variations in their mode of action. Mycorrhizae form a symbiotic relationship between a fungus and the roots of a plant. They assist with nutrient uptake as well as provide protection for both abiotic and biotic stress.

Entomovectoring is a concept where pollinating insects are utilised to disseminate beneficial microbial controlling agents to target crops. Bumble bees have been commercially applied to

greenhouse crops for the purpose of effective pollination. More recently, they have been utilised for entomovectoring on a commercial application in greenhouse hydroponic berry production systems. Unfortunately, bumble bees are forbidden on mainland Australia and therefore honeybees are the next possible vector.

The intention of the author was to explore and assess IPM strategies globally and to then identify emerging and innovative technologies available for commercial application in the greenhouse hydroponic berry industry in Australia.

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# Foreword

My entry into the Zimbabwean floricultural sector was underpinned by the opportunity to compete on a world stage as 100% of the greenhouse produced rose crop was exported to Europe as fresh-cut blooms. This also meant an expectation of minimum quality standards, of which pest and disease-free as well as blemish and damage-free product was required. The only tool at our disposal to assist in attaining these quality standards was a chemical option. Resistance reared its ugly head very soon and it remained an ongoing issue.

A rather traumatic disruption to the family mixed farming enterprise in Zimbabwe in early 2000 was hastily exchanged with the objective to gain entry into and permanent residence of Australia. Specific visa obligations and requirements had to be fulfilled within a 36-month period from initial entry and this provided extra tension as securing tenure and establishing a business with limited resources became challenging. The consensus to revert to intensive floriculture production eased the initial relocation anxiety as previous knowledge and experience gained was applicable in our newly adopted country of residence.

Within months of establishing a greenhouse hydroponic rose cut-flower production facility, an opportunity to peruse IPM strategies availed with the assistance and guidance of the NSW Department of Primary Industries. The ability to significantly reduce chemical applications to the rose crop became abundantly clear and the adoption of basic IPM practices took place immediately within the project. Despite this type of crop essentially remaining inedible, there was immense comfort in the fact that these roses were exposed to a very limited number of chemical applications (in most cases as a last resort).

The recent increase of imported roses into Australia at below current cost thresholds for local growers has increased pressure and lead us to explore alternative niche type crops to continue cultivating within our intensive production facility. Berry crops were identified and to date, we have planted blueberries, raspberries and strawberries. By sheer coincidence, the latter two are also members of the Rosaceae family and to an extent exhibit and present similar growing as well as pest and disease management requirements.

***Figure 1: Wade Mann in glasshouse strawberries at Kearns Farms in Ireland (Source: N. Mann, May 2016)***

# Acknowledgments

An abundance of successful horticultural applicants in the Nuffield 2015 intake stretched sponsorship opportunities and by a stroke of serendipity, Nuffield Australia stood by their actions and graciously committed to sponsoring my scholarship opportunity. I have the utmost respect and appreciation for the decision the Nuffield Australia Board took in this regard.

My greatest inspiration for furthering my initial taste of IPM has been through the dedicated training and knowledge transfer from Stephen Goodwin, Marilyn Steiner and Len Tesoriero. Previously working out of the National Centre of Excellence for Greenhouse Horticulture in Gosford on the NSW Central Coast, they provided me with invaluable information in both pest and disease control through IPM. Bettina Gollnow was instrumental in organising and facilitating grower day meetings of the then NSW Rose and Gerbera IPM Group. They are four professionals who I hold in high regard and acknowledge their valuable input in the IPM arena in Australia.

Marcus Kroek has provided me with invaluable tutelage in his role as our business coach, for which I am extremely grateful.

The “Ninjas” of the inaugural Japanese Global Focus Program (GFP) 2015 were a pleasure to travel and share global agricultural experiences with. The friendships and memories created over the GFP journey will remain forever. Thank you for your companionship and valuable contributions, Maire, Holly, Bernadette, Robert and James. Thanks also to Michael Chilvers in Singapore, Mick Sheehy in Indonesia, Jodie and Wayne Redcliffe in Japan, Djuke and Henk Smith in Netherlands, Lillian Lipton in Washington and Ed Kee in Delaware, USA for hosting the Ninjas on tour.

My travels included many visits to research centres, universities, biological suppliers/manufacturers and a diverse range of intensive primary producers from small-scale owner/operator to multinational producers of horticultural fresh produce. I am forever grateful for your valued input and kind hospitality in hosting me.

The production and retail staff of Roses 2 Go P/L are to be commended on their attitude and commitment to the business with a “Mann” down. They have grown in character and learnt to deal with unpredictable situations professionally. Forwards ever, backwards never!

Despite my parents, Tony and Merle, living in Western Australia – I am extremely fortunate to have their backing at all times. They have provided my immediate family with

encouragement and unrelenting support in my periods of absence. I am proud of the relationship they both have with my children and engender the morals and values that our family live by.

Last but by no means least; I owe my deepest gratitude to my devoted wife and children. My two sons are proudly serving in the R.A.N. whilst my daughter completes her final year of her HSC having completed an overseas exchange program last year. They have been most accommodating and considerate since their parents have embarked on consecutive Nuffield Scholarships over the last two years. They have shown maturity and assumed responsibility well beyond their years. They have never hesitated to get their hands dirty and support the business in all regards - thank you Zinzan, Tayne and Oregan for your understanding.

Finally, my Nuffield #cougar has been my motivation and inspiration throughout my Nuffield journey. Nicky has endless enthusiasm and energy for our combined horticultural pursuits and I remain eternally grateful for her partnership in our endeavours. Nicky exudes warmth and abundance of the heart and I am fortunate to have a wife and partner of her quality.

# Abbreviations

a.i. – active ingredient

APVMA – Australian Pesticides and Veterinary Medicines Authority

BCA – Biological Control Agents

B.t – *Bacillus thuringiensis*

CRS – Controlled Release Sachets

e.g. – Example

EMR – East Malling Research

EMF – Entomopathogenic Fungi

EN – Entomopathogenic Nematodes

etc – et cetera meaning 'and so forth'

DPI – Department of Primary Industries

FAO – Food and Agriculture Organisation of the United Nations

GAP – Good Agricultural Practices

i.e. – That is

IPDM – Integrated Pest and Disease Management

IPM – Integrated Pest Management

IPPM – Integrated Plant Production Management

JA – Jasmonic Acid

Medfly – Mediterranean Fruit Fly

MRL – Maximum Residue Level

NSW – New South Wales

QFF – Queensland Fruit Fly

RAN – Royal Australian Navy

REI – Re-Entry Interval

RHP – Regeling Handelspotgronden (Dutch certifying authority for potting mixture)

SA – Salicylic Acid

SAR – Systemic Active Resistance

SWD – Spotted Wing Drosophila

TSWV – Tomato Spotted Wilt Virus

WHP – Withholding Period

WFT – Western Flower Thrips

# Objectives

In an endeavour to tackle this study topic, the author chose to:

- Explore and assess global best practice IPM strategies for greenhouse hydroponic berry crops.
- Identify emerging and innovative technologies associated with biological control agents (BCAs) available for commercial application whilst maintaining overall quality of soft fruit.
- Consider and gauge the feasibility of adopting entomovectoring in a commercial greenhouse environment for berry production.
- Make practical and commercially viable recommendations to growers adopting IPM in intensive greenhouse hydroponic production of berries within Australia.

# Chapter 1: Greenhouse Hydroponic Berry Crops

The berry (strawberry, blueberry, raspberry and blackberry) industry in Australia is currently enjoying the title of the fastest growth sector in the fresh produce category on supermarket shelves, nationwide. In recent years, globally and domestically, berries have acquired an extremely positive health attribute status. They are renowned for their apparent high anti-oxidant properties; good levels of omega 3's; multiple vitamin presence and low glycaemic load (Curejoy Benefits of Berries, 2016). In Australia today, the demand for berry fruit by consumers is bordering on insatiable.

By virtue of their nature, berries are seasonal and require varying degrees of chill hours (vernalisation) to induce and promote flowering and ultimately fruiting. Growers have sought to extend the growing season by manipulating the growing environment through the investment in sophisticated protected cropping structures. Substrate production has also seen increased adoption to control and refine conditions in the root zone of the various berry types.

These modifications of the environment through enhanced climate control as well as a more consistent growing medium have led to increased yields in fruit production but equally important, a better-quality fruit in appearance, size and durability. These characteristics may be attributed to a more balanced growing season with less extremes and variations in climate and nutrition. Inadvertently, these adjustments (in response to creating a more suitable environment for intensive berry cultivation) have resulted in conditions conducive to the proliferation of pests and diseases.

The notable versatility and ready-to-eat soft fruit is underpinned by its edible skin, as peeling is not required. However, there have been reports of the visual presence of chemical residues on the soft fruit and this has led to more stringent market requirements. Customers are rightfully reluctant to purchase any berry or fresh product with visually detectable pesticide residues.

Government legislation as well as supermarkets has increasingly applied pressure on primary producers to ensure conformity with regard to Maximum Residue Levels (MRL), With Holding Periods (WHP) and utilisation only of registered chemical products for pest and disease control.  Accreditation schemes have been developed to ensure compliance in this regard and remain a pre-requisite for primary producers intending to supply the major supermarket chains.

From a primary producer perspective in the berry industry, there have been various obstacles to contend with in pursuit of these consumer and supermarket demands including pest and disease free berries, absence of pesticide residues and fulfilment of MRL's. Issues pertaining to limited chemistry availability and subsequent pesticide resistance probability, minor use status as well as social and environmental considerations become limiting in regards to the primary producer's intentions and aspirations to meet these requirements.

In Australia, each berry type has an independent association and the onus is on these industry body organisations to register chemical products necessary for pest and disease control of that specific berry type. The significantly modest berry production area in comparison to broad acre crops relegates this industry into the minor use category. This has created limitations for chemically-based pest control.

As a result of these above mentioned limitations, adoption of IPM strategies have become the next best option to assist in pest control. Although this technology is a relatively new option to the berry industry, there have been some rapid and significant developments in this arena and certainly increasing in the rate of implementation and adoption.

## The IPM concept

There is still not one universally adopted definition for IPM. There is a plethora of variations and interpretations of the meaning of IPM, and whilst mostly credible, it is a case of understanding the fundamentals and options on offer for crop protection and ultimately decision making.


***Figure 2: Compendium of IPM Definitions by Waheed I. Bajwa and Marcos Kogan from Integrated Plant Protection Centre (IPPC) at Oregon State University, Corvallis.*** (Kogan, 2002)

It is interesting to note a recent FAO interpretation of their definition of IPM based on global crop production and protection (FAO, 2016):

*"IPM is an ecosystem approach to crop production and protection that combines different management strategies and practices to grow healthy crops and minimize the use of pesticides. IPM is an approach-based method for analysis of the agro-ecosystem and the management of its different elements to control pests and keep them at an acceptable level (action threshold) with respect to the economic, health and environmental requirements."*

IPM includes the necessary phytosanitary measures, monitoring and diagnostic system, good agricultural practices (GAP) and the management of natural enemies with the minimum amount of pesticides (when needed and good quality). IPM is thus an important part of Integrated Plant Production Management (IPPM) and sustainable crop production intensification. By enhancing the ecosystem function, by making the agricultural ecosystem healthier, more ecosystem services are provided: in this case – pest control (FAO, 2016).

In essence, IPM is a common sense, proactive approach to crop protection which gives due consideration to the following steps:

- Monitoring and scouting to detect initial pest and disease presence and then the levels of infestation.
- Recording of pests and diseases, to log and track increases or decreases in pest and disease densities, the area of infestation within the crop and specific location of individual plants.
- Recording data on climate and weather forecasting, seasonality of crops, pests and disease, and surrounding cropping programs.
- Establishment of economic thresholds to assist in correct timing of application of the control strategy.
- Predicting and assessing economic, ecological and sociological consequences.
- Selection, integration and implementation of cultural, physical and biological control strategies.
- Utilising chemical controls as a last resort and giving due consideration to the choice of pest or disease-specific products with the least toxic formulation and using an alternative chemical group where applicable.

## Plant health management

In order for a plant, including all berry species, to reach optimal commercial potential, seven aspects of plant health need to be considered (refer Figure 3). A compromise in any one or more of the sectors may ultimately lead to a situation where adjustments are consistently required and fail to address the underlying issue.

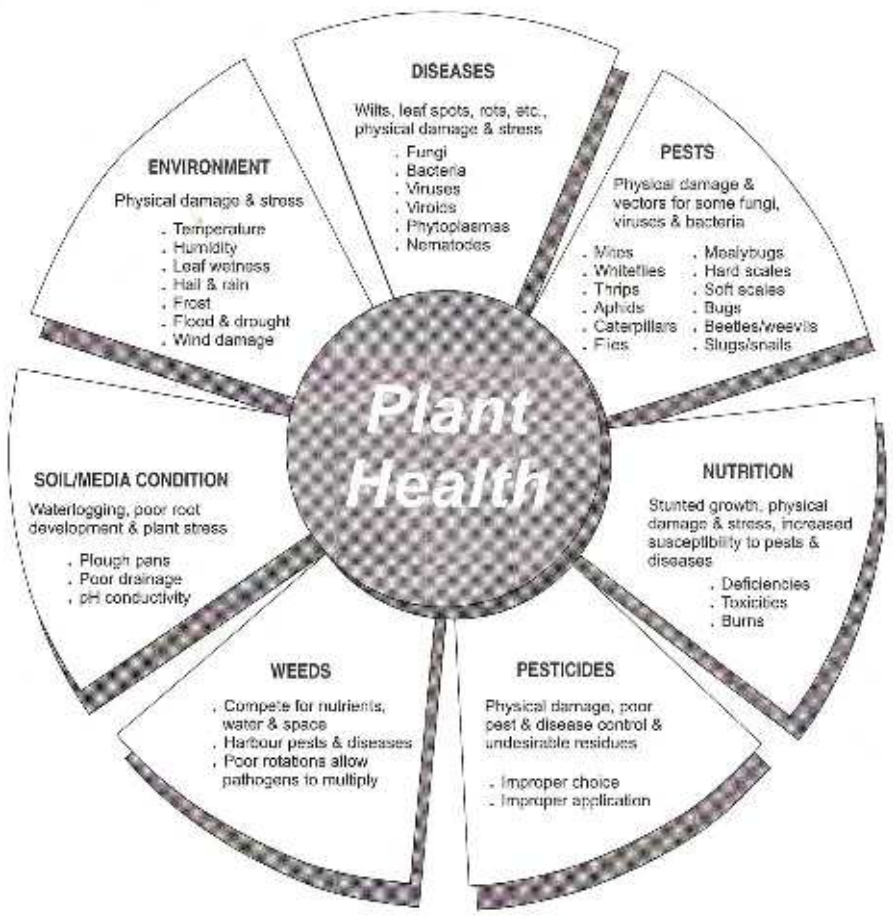


***Figure 3: The Seven Sectors of Plant Health. (Dr Stephen Goodwin, 2002)***

## Basic fundamentals needed to establish an IPM program

### *Scouting/monitoring*

In order to establish pest/disease presence and then pressure, berry crops must be routinely scouted. This is achieved by sticky trap, biased and random inspections. *A biased inspection* includes focusing on obvious, visual symptoms of poor plant health and pest presence e.g. wilting, yellowing, insect damage. *A random inspection* involves plotting a route through the berry crop and randomly stopping at regular check points to detect pest or diseases before they produce obvious symptoms. Above and below ground scouting methods must be undertaken to assess root, vegetative and generative plant physiology. (In this case, the information must be recorded and ranked according to levels from low to high incidence.) This same program of inspections should be repeated at regular intervals in the cropping program and follow the same route and sequence of check points to gain an accurate assessment of the level of infestation and ultimately, an indication of the level of control needed after a control strategy has been adopted and applied.

*Sticky traps* are colour specific (yellow or blue) pieces of flat card covered with a waterproof adhesive. They are generally rectangular in shape and measure roughly 15x25cm. They are positioned just above the berry crop (and will require lifting as a crop like raspberries, blackberries and blueberries grow vertically) and are initially set up at approximately one trap per 200m². Sticky traps are used for attracting and trapping flying pests only. They should be inspected at regular intervals and analysed for pest type and numbers present (refer Figure 4). This information must be recorded and graphed to easily determine level of infestation or pressure throughout the cropping cycle (Dr Stephen Goodwin, 2002).

***Figure 4: Wade Mann inspecting a yellow sticky strap. (Source: N. Mann, Woongarrah, NSW April 2015)***

### *Recording*

Data from all sticky traps, biased and random inspections should be retained for record keeping.  This information is critical to gauge detection and the level and trend of infestation. By graphing these records, a clearer picture is presented from which developing an informed decision is simplified. It also clearly demonstrates the effectiveness of a selected control measure after application, as any change in the pest or disease infestation levels should be apparent.

### *Pest identification*

It is essential that correct pest identification is achieved to ensure appropriate control strategy is selected for a positive outcome. Pest identification resources should be accessed in doubtful situations or potentially referring the pest sample to a diagnostic facility to assist in confirmation of pest identification.

### *Action threshold*

This is the point at which an intervention must be applied to prevent the pest population or disease development from reaching economic damage, based on accurate monitoring data and records (refer Figure 5). This point remains variable and difficult to determine according to berry crop type and age. The action threshold should include consideration of development stage (vegetative or generative) and the control strategy to be implemented i.e. biological control methods should be actioned early on, to build up biocontrol agents but chemical control treatment may be delayed due to their instant effect.

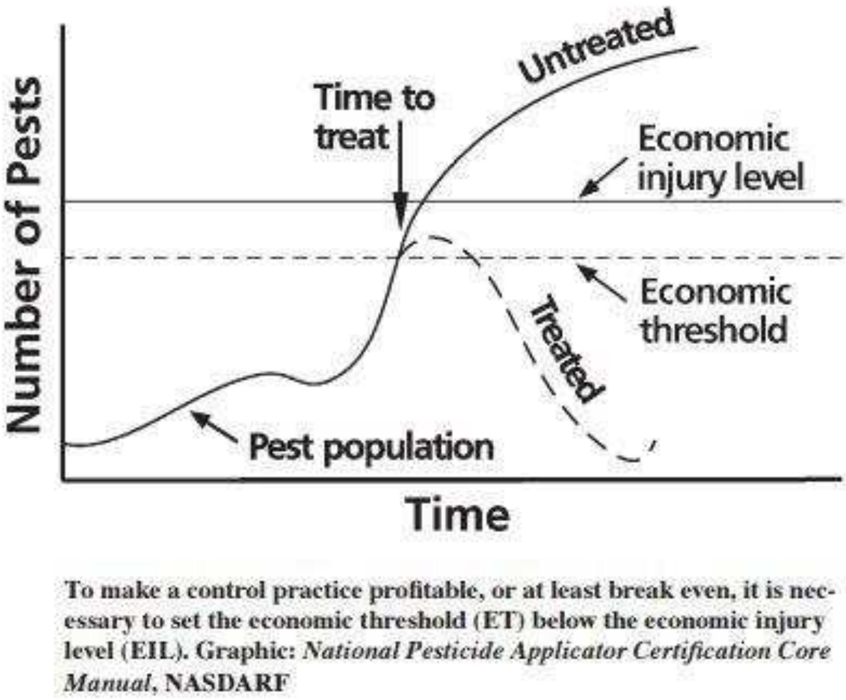


***Figure 5: Action Threshold Graph from University of Minnesota document on IPM***
(Minnesota, 2014).

# Chapters 2: Physical controls

This section of IPM strategies focuses on the methods and options to enhance the growing environment of berry crops and the protection from the various climate and naturally occurring pest elements. There is an abundance of tools available to physically manipulate and steer the climate, according to the berry crop demands as well as attempting to reduce pest and disease incursion or proliferation. The main limitations and variations in the levels of controls implemented are related to the level of investment and cost/benefit outcome. The following improvements are commonly considered:

- Steel-type structures from basic single span tunnels to contemporary multi-span greenhouses entities, which are fast becoming adopted by the berry industry around the globe to increase yield but also to offer protection from pests, diseases and the climatic elements.
- Covers of netting (hail and bird) to shade cloth (varying colours) to polythene (clear, diffused, woven, single and twin-layered) to the ultimate in tempered glass to protect berry crops from the climate and pests.
- Ventilation systems from permanent or fixed open ends to roll-up side vents to moveable top, ridge vents, which are used for assisting with temperature and humidity control as well as air movement within the protected structures.
- Screens within the greenhouse structure can be used for purposes ranging from insect exclusion (varying aperture sizes) to shading (various options on percentage of shade required to total blackout screens) to thermal screen (cold climates). Physical controls against pests gaining access to the delicate berry crops to manipulating the environment for optimum plant health and performance.
- Heating options from fan forced systems, to complete hydronic pipe and rail systems – manipulating the temperature has a significant impact on the berry crops health and well-being keeping them in optimum conditions for maximum growth and strength against insect attack.
- Cooling from horizontal air flow fans to overhead misting and fogging to assist the berry crops with temperature control, assist pollination, discourage pests and diseases and additionally minimise stress in the berry crop.
- Floor covers from permanent green covers to gravel aggregate to weed exclusion mat (darker colours) to reflective mats for enhancing lower-canopy light penetration.

- Raised growing benches (various configurations from single table-tops, to double and triples) to assist with ventilation, drainage, light and plant maintenance.

There have been advancements in the utilisation of "non-commercial" plant types to provide a range of options for growers in managing and implementing pest control strategies. Most of these sacrificial plant types are interspersed within the greenhouse berry crop, but may also be cultivated externally as a strip or buffer zone.

- Banker plants – providing a host for mostly non-pest organisms in a mini-rearing type system for arthropod Biological Control Agents (BCAs). For example, cereals are monocotyledonous plants and only provide a food source for a non-pest organism such as cereal aphids to feed on, and ultimately provide a food source or host for the establishment of the host specific parasitic wasp (Valentia, 2011). Refer to Figure 6 and 7 below.

***Figure 6: Wheat being used as a banker plant for a host-specific parasitic wasp. (Source: Biological Services Australia Website)***

***Figure 7: Cereal banker plant underneath glasshouse strawberries. (Source: W. Mann, Keelings, Ireland May 2016)***

- Indicator and trap plants – these "pest-preferred" plant types provide an early pest detection opportunity as an indicator (refer Figure 8) and also combine to serve as a trap plant through generous releases of Arthropod BCAs or alternative control strategies such as mechanical vacuuming, relocation of plants or chemical application e.g. vetch is attractive to Western Flower Thrips (WFT) and suitable for *Orius sp.* released as arthropod BCA. Lucerne is attractive to Lygus bugs and easily accounted for by chemical control.

***Figure 8: Bean indicator plant amongst glasshouse tomatoes. (Source: W. Mann, Chatham, Canada July 2015)***

- Companion plants – serve in a greenhouse berry crop to attract pollinators through good pollen source, but also to provide various arthropod BCAs with pollen as an alternative food source when pest incidence is low. Borage is commonly used for this dual purpose in greenhouse berry production – attracting honey bees for pollination and providing an alternative food source (pollen from Borage) for *Orius sp.* (refer Figure 9).

***Figure 9: Borage used in blueberry tunnel production to attract honey bees into the middle of the tunnels. (Source: N. Mann, Corindi, NSW Sept 2015)***

- Nature strips – selection of herbaceous flowering strips commonly planted along external borders or in between greenhouse berry structures (refer Figure 10). These flowering plants impact on insect behaviour by attracting natural enemies and favouring arthropod BCA development e.g. coddling moth are attracted to an abundance of pollen and nectar (Integrated Pest Management working with nature, 2016).

***Figure 10: Nature strips of flowers outside berry tunnels in Huelva, Spain. (Source: N. Mann, May 2016)***

# Chapter 3: Cultural controls

The main focus of cultural control is to alter the environment, the condition of the host or the behaviour of the pest to prevent or suppress an infestation. It disrupts the normal relationship between the pest and host and makes the pest less likely to survive, grow or reproduce (Private Pesticide Applicator Training Manual Edition 19, n.d.). Many cultural practices may be adjusted through berry crop management techniques.

***Figure 11: Glasshouse strawberry production showing good biosecurity practices. (Source: W. Mann, The Netherlands May 2016)***

The notable areas to consider include:-

- Propagation material – tissue-cultured plugs are produced under strict biosecurity controls, ensuring this plant material is of superior quality and pest and disease free. There is a massive shift by berry breeders to providing tissue-cultured plants for crop establishment (Bermuda, 2016).
- Plant nutrition – a well-balanced crop feeding program and a frequency of application consistent with the developmental stages of the crop mitigates deficiencies or toxicities during plant growth. Correct pH regulation is fundamental to nutrient availability and must be monitored routinely. Excess nitrogen leads to lush, soft vegetative growth increasing susceptibility to pathogen attack. It also impacts fruit quality by compromising taste, shelf life and disease tolerance.

- Water management – irrigation scheduling and application must accurately account for solar radiation levels, crop stage, substrate performance and the capacity of system. Anaerobic conditions in the root-zone lead to disease issues, such as damping-off. Under-watering leads to abiotic stress and pathogen susceptibility.
- Growing media – the main issue concerning berry production in substrates deals with particle size and moisture retention capacity relative to air porosity. Poorly draining substrates create damping-off type disease prevalence, usually as a result of excess fine particles in the substrate.
- Crop maintenance – whilst berry crops require different techniques to reduce excess vegetation, the aim is to maintain sufficient air movement and light penetration throughout the berry crop canopy to reduce pathogen incidence.
- Genetics and resistance – undoubtedly, good genetics relate to vigour and superior overall productivity relative to environmental conditions and management inputs. Coupled with specific breeding traits to remain resistant to pathogen incursion, the potential advantages are well founded. An example of this is the "Hairy Cane Trait & Resistance to Cane Disease - Gene H" (Jennings, 2016). Refer Figure 12.

***Figure 12: Nikki Jennings from James Hutton Institute (JHI) and Wade Mann discussing genetics and breeding in raspberry plants. (Source: N. Mann, JHI Scotland May 2016)***

# Chapter 4: Chemical controls

Pesticides are an integral and important input in Australian agriculture. Their use and importance are increasing as primary producers strive to remain competitive both domestically and globally. The use of pesticides has greatly increased world food security and standards of living. Primary producers and their industry bodies recognize market and community demands for crop production systems which ensure continued, safe, wholesome produce with technologies that remain environmentally sustainable.

The introduction of Quality Assurance (QA) schemes by the large food retailers in Australia provides a potentially powerful force aimed at ensuring a low pesticide residue status in domestically consumed foods. Pesticide usage requires an evaluation of the benefits in relation to the costs of its introduction (efficacy and economy of use) but also in terms of the hazard (inherent chemical properties potentially capable of causing adverse effects) and the risk (probability that harm is realised) under a particular set of conditions where the pesticide is to be used. Pesticides are generally perceived as a necessary evil.

Pesticides are necessary because of the global demand for food with the high cosmetic standards demanded by consumers. There are also strong economic forces on producers to remain competitive, while meeting stringent requirements by quarantine for trade. Pesticides represent the only rapid method of intervention when pests exceed levels causing economic damage.

Pesticides are considered to be evil because they are generally acknowledged to have a potential negative impact on our health and environment, and because their use may lead to problems of pest resurgence, secondary pests and pest resistance.

## Chemical registration

Chemical manufacturers seeking Australian Pesticides and Veterinary Medicines Authority (APMVA) registration of new products typically limit the scope of the application to the envisaged major uses for the chemical. The wider the scope, the greater the overall cost of the application due to costs involved in data generation, particularly in regard to chemical residue data for food crops. Unfortunately, as in the case of the berry industry, manufacturers will generally not make the investment needed to develop, register or maintain products for 'minor-use' markets where there is anticipated to be an inadequate net economic return.

With reference to the chemicals currently registered for the four main berry categories (blueberries, strawberries, raspberries and blackberries) in Australia, it is worth noting that despite a limited number of products, there is generally more than one different chemical group registered per pest or disease. This is essential, ensuring it is possible to rotate chemical groups to reduce resistance formation by pests and diseases.

There is an excellent published document for chemicals registered for berry plant protection in Australia which even rates the chemicals and their impact on beneficials. It is advisable to refer to the Berry plant protection guide 2016-2017 released by NSW DPI when considering chemical control in berries (Wilk, Simpson, & Brown, 2016).

There has been a noticeable shift away from broad spectrum chemical products that are generally more toxic and are also classed as 'hard' pesticides, towards those products that are more host-specific, efficacious and generally less toxic and classed as 'soft' pesticides.

It is strongly advisable to refrain from indiscriminate and judicious application of pesticides as preventative/prophylactic control. Ideally, they should be limited to a curative option when action thresholds have been met. A priority should be given to only controlling biotic threats when absolutely necessary, in order to reduce the probability of resistance occurring.

Climate, geography, pests and products vary from location to location and as a consequence there are different limits for particular residues of specific products.

# Chapter 5: Biological controls

Biological control is the use of natural enemies (including predators, parasitoids and pathogens) as Biological Control Agents (BCAs) to manage or suppress both pests and diseases – “a population levelling process” (MacDonald, 2016). These BCAs may be naturally present in the greenhouse berry crop or may be commercially produced by a biocontrol rearing agent who then supplies the recommended or required BCA in bulk for release into the greenhouse environment. There are biological chemical products where the active ingredient is derived from a living organism (plant, animal, microorganism, etc.) with or without modification ( Guideline for the regulation of biological agricultural products, 2014).

## Strategies of biological control methods

The three main strategies of biological control include classical methods, augmentation and conservation biocontrol (New World Enclyclopedia, 2016).

Classical control – greenhouse berry cultivation provides an opportunity to establish production facilities in various geographical locations. Often when pest incursions occur, there are few ‘locally’ occurring natural enemies in abundance. The classical method of importing and releasing BCAs becomes the selected or preferred option. *Encarsia formosa* has been utilised globally as a first line of defence for silver leaf whitefly in numerous crops. *Encarsia formosa* is ubiquitous globally and easily adapted to greenhouse environments and the diversity of crops grown within these structures.

Augmentation – this involves mass rearing and then releasing of arthropod BCAs into crops either in a preventative form of biological control or due to an imbalance in arthropod BCA to pest presence. By enhancing the number of BCAs, balanced pest numbers is the aim. Two-Spotted Mite (TSM) generally occurs when weather conditions change from cool to warm in a short period of time (winter to spring). Through anticipation of TSM proliferation in greenhouse strawberries in September, further releases of Phytoseiulus persimilis will be implemented in good time.

Conservation control – this includes modifying the environment and the conditions to better suit BCAs. In a greenhouse system this is achievable through retention within the structure of BCAs by eliminating disruptive conditions like wind, rain and extreme temperatures. It is also possible to maintain conservation of BCAs through the integration of banker plants, pollinator plants and companion plants within the greenhouse berry crop.

## The common insect pest issues for the greenhouse berry industry

The four common global insect pests creating issues within the greenhouse berry sector include: thrips, two spotted mites, aphids and whitefly. Whilst Australia has a range of commercially produced BCAs available for the domestic berry sector, the objective of this report was to investigate alternative options for IPM strategies outside Australia to highlight any shortfalls that may exist and which may affect our production potential in greenhouse berry cultivation.

Koppert Biological Systems are an internationally recognized market leader in biological crop protection (indoor and outdoor) and natural pollination with a global presence. Despite having no commercial interests in Australia, they were generous in hosting the author and forthcoming in delivering their version of pathways to successful implementation and integration strategies specific to greenhouse hydroponic berry production. They have focused their attention, in regard to the berry sector, on the following pests, with specific BCA options, relative to climatic variation or specific requirements.

**Thrips** - they are global in distribution and occur in many variations, but Western Flower Thrips (WFT), *Frankliniella occidentalis* is becoming a massive challenge to greenhouse berry growers due to its evasive nature and in its resistance-forming capabilities to chemical control. Thrips cause damage to the plant by piercing (with a rasping action) and sucking out cell contents on the leaf surface. This impacts plant production potential. WFT also target flowers and causes cosmetic damage to the petals which results in blemishes on the fruit, often reducing its consumer appeal, causing lower financial returns to the grower. WFT also have the ability to vector and transmit viruses such as Tomato Spotted Wilt Virus (TSWV).

Arthropod BCAs applicable to WFT control:-

- *Neoseiulus cucumeris* is a temperate climate predatory mite more effective in early spring or late autumn for WFT control. *Amblyseius swirskii* is also a predatory mite but in contrast, it is more effective in higher temperatures and low humidity conditions without hindering performance in WFT control. *Amblydromalus* *limonicus* is a new and sensational predatory mite with the ability to control WFT at higher levels of infestation and in various stages of thrip larval development.

- *Orius laevigatus* is a predatory 'pirate' bug that consumes all stages of thrip development.

***Figure 13: Orius armatus on strawberry flower. (Source: W. Mann, Woongarrah, NSW Dec 2015)***

***Figure 14: Orius armatus in a novel dispenser with buckwheat above a young greenhouse raspberry crop. (Source: N. Mann, Woongarrah, NSW Dec 2015)***

The current situation in Australia – Australian BCA suppliers has commercially reared *Neoseiulus cucumeris* and the equivalent of *A. swirskii* in *Transeius montdorensis* as high performance WFT predatory mites. *Orius armatus* has recently been commercially developed for greenhouse berry crops, as this pirate bug feeds on pollen when target pests are at low levels (refer Figure 13 and 14). *O. armatus* is winged which may create retention problems if greenhouse protective covers on tunnels structures are lifted to assist ventilation in warm periods. *A. limonicus* is not commercially available in Australia.

The synopsis – *N. cucumeris* and *T. montdorensis* afford the greenhouse berry grower control of WFT in a range of temperatures. *N. cucumeris* does not function on plants where trichomes are present on the leaf (raspberry varieties) or stems. *N. cucumeris* and *P. persimilis* (specialist TSM predatory mite) are not compatible under low pest pressure due to predation of *P.persimilis* by *N.cucumeris*. According to Peter Melis, of PC Hoogstraaten in Belgium, *A. limonicus* is a very expensive BCA due in part to recommended high density release rates (Melis, 2016). *O. laevigatus* is not as effective on June-bearer strawberries due to short, seasonal production windows. Jean Fitzgerald from East Malling Research (EMR) station endorsed this observation with regard to *N. cucumeris* in June bearer strawberries, as *N. cucumeris* does not diapause/over-winter during the non-productive period of June bearer strawberries and is difficult to retain in situ until the next impending productive phase (Fitzgerald, 2016). Koppert Biological Systems undertook in-house trials for WFT on a predatory thrip, *Aeolothrips tenvicornis* (found in Australia) and although the results were satisfactory, difficulties in commercial rearing made this pest too expensive to use.

**Two-Spotted Mites** – are a common but major pest globally due to their broad host range, efficient reproductive capacity, short generation time and increased resistance to pesticides (refer Figure 15). They are very damaging under hot, dry conditions (Dr Stephen Goodwin, 2002). TSM infestation is very taxing to the plant as they are a sucking pest and feed on the underside of leaves resulting in decreased plant growth and production (Koppert Biological Systems).

Arthropod BCAs applicable to TSM control:

- *Neoseiulus californicus* – feeds on a range of spider mites species and is available in a loose mix bottle or controlled/slow release sachets (CRS) – ideal for gradual release over 6 week period.

- *Phytoseiulus persimilis* – is a very aggressive natural enemy of TSM and used to remedy hotspots successfully (Koppert Biological Systems).

The current situation – *P. persimilis* is limited to successful rearing on plants only. As a result there is no Controlled Release Sachet (CRS) option. The carrier product commonly used to enhance distribution more consistently within berry crops is vermiculite (refer Figure 16). Observations by Cristian Miamandu from Haygrove, Ledbury indicate vermiculite tends to roll off leaf surfaces easily in the berry crops, displacing the predatory mites (Miamandu, 2016). They were trialling sawdust as an alternative carrier to mitigate this issue. In Australia, both arthropod BCAs are available but *P. persimilis* is highly regarded as effective TSM control of all greenhouse berry crops.

The synopsis – from a global perspective, both *P. persimilis* and *N. californicus* are widely used as effective TSM arthropod BCAs. Sulphur based products reduce their ability to gain an upper-hand on TSM control. Johan Otto, from Special Fruit, Huelva in Spain has established that *N. californicus* is more beneficial in hot weather conditions (Johan Otto from Special Fruit, 2016). Both arthropod BCAs are available commercially in Australia.

***Figure 15: Greenhouse raspberry plants heavily infected with TSM. (Source: N. Mann Woongarrah, NSW Feb 2016)***

***Figure 16: P. persimilis in vermiculite scattered on raspberry leaves in greenhouse production. (Source: N. Mann, Woongarrah, NSW Feb 2016)***

***Figure 17: P. persimilis arriving in polystyrene boxes in express post. (Source: N. Mann, Woongarrah, NSW Feb 2016)***

**Whitefly** – both Silverleaf Whitefly (*Bermisia tabaci*) and Greenhouse Whitefly (*Trialeurodes vaporariorum*) are major pests in many fruit and vegetable crops globally. Greenhouse conditions are favourable for the establishment and infestation of Greenhouse whitefly in raspberry and strawberry production. Both adults and larvae extract food from the leaves of the plant and impact physiological processes and reduce growth. They also have ability to vector and transmit viruses, leading to catastrophic economic damage. Larger larvae secrete honeydew whilst actively feeding – which leads to development of sooty mould and ultimately a reduction in photosynthesis in the berry plant as a result.

Arthropod BCAs applicable to Whitefly control:-

- *Amblydromalus limonicus* – this predatory mite targets both the egg and larval stages of both whitefly types in lower, milder temperature regimes. Released in loose form only.
- *Amblyseius swirskii* – also a predatory mite targeting both egg and larval stages but is supplied in CRS and has better capabilities in higher temperatures (refer Figure 19).
- *Encarsia formosa* and *Eretmocerus eremicus* – are parasitoids released in combination or separately targeting the second and fourth larval stages. They are released as parasitized whitefly pupae on cardboard strips and hung on the crop leaf stems for dispersal into the greenhouse berry crops (refer Figure 18). Both parasitoids are more effective in warmer temperatures and extended day-lengths (*E. eremicus* more so in extremely warm conditions).

The current situation – both *A. limonicus* and *A. swirskii* are generalist predators and therefore versatile in controlling a range of pest issues. *E. formosa* and *E. eremicus* are parasitoids specifically targeting whitefly infestation. Both have limited flying range and must therefore be released throughout the greenhouse berry crop production area. All forms of these arthropod BCAs are impacted by sulphur products.

The synopsis – a release of generalist predators when pest incursion is low is beneficial. However, if two or more pest types begin to dominate in tandem, the predatory mite may take preference in controlling one pest over the other. The option to release parasitoids must therefore be timely to mitigate excess pest pressure. In Australia, a new arthropod BCA in *Nesidiocoris tenuis* has been commercially released by Biological Services, Loxton in South Australia. This recent commercial option of predatory bug will actively feed on all stages of whitefly but only parasitizes the pupal stage. It is a generalist predatory bug that will also target mites, thrips and even moth eggs. Whilst it has been used extensively in greenhouse tomato and eggplant production it is still in the trial phase for other greenhouse crops, including berry crops. The only apparent drawback is under low pest presence, when *N. tenuis* will actively feed on the greenhouse crop and therefore monitoring is essential.


***Figure 18: Eretmocerus sp. in glasshouse tomatoes. (Source: N. Mann, Canada Oct 2014)***

***Figure 19: A. swirskii in glasshouse strawberries. (Source: W. Mann, The Netherlands May 2016)***

**Aphids** – are also very common, widespread globally and problematic in their enormous reproductive capability within the berry sector (refer Figure 20). The nymphs and adults feed on plant sap which leads to reduced plant growth and cause possible leaf curling or yellow spots developing. Aphids excrete honeydew providing a host for sooty mould development which reduces the photosynthetic rate and ability of the plant and ultimately leads to stunted growth. Aphids are also potential vectors and transmitters of plant-pathogenic substances such as viruses.

***Figure 20: Aphids heavily infesting a tunnel blueberry crop with a predatory lady beetle coming in to feed. (Source: W. Mann, Huelva, Spain May 2016)***

***Figure 21: Parasitised aphids on trap plant. (Source: W. Mann, Woongarrah, NSW Mar 2016)***

Arthropod BCAs applicable to Aphid control:-

- *Aphidius colemani*, *Aphidius matricariae*, *Aphidius ervi* and *Aphelinus abdominalis* – these are all parasitoids favouring an array of aphid pest species commonly found in greenhouse berry crops. *A. colemani* is adaptable to higher temperatures than *A. ervi* for example – but the combination covers for a range of temperatures. They may be released individually as parasitized aphid pupae on cardboard strips or as mummies bottled with inert carrying material.
- *Chrysoperla carnea* – is a predatory lacewing where the larval forms attacks prey and sucks out the body fluids. Adults emerging from pupae generally fly away and do not contribute to control. The larvae are only effective on low crops like strawberries or young developmental stage of other berry crops.

***Figure 22: Parasitic wasp dispenser and holder above glasshouse strawberries. (Source: W. Mann, Belgium March 2015)***

The current situation – a combination release of parasitoids for aphid control is beneficial due to the vast array of different aphid species potentially inhabiting greenhouse berry crops (refer Figure 22). This 'insurance policy' type approach also assists in identifying the particular aphid species when parasitized and a follow-up release of the individual parasitoids type within the pest location results in early suppression of the pest. *A. abdominalis* does not disperse well and must be released in close proximity to the pest aphid colony to be effective as a BCA.

The synopsis – in Australia, *Mallada signata* is a native generalist predator used in greenhouse systems. They perform better under warm conditions. It would appear that on the information provided by Koppert Biological Systems, losses are prevalent during the adult lacewing stage after wing development and this may impact on the acquisition as a BCA. The commercial combination of parasitoids available in Australia meets the required control levels as observed in Europe.

## Other insect pest issues of the greenhouse berry industry

In this category, there are insect pests that are either of lesser importance in comparison to the previous four common global insect pests, or these pests are currently localised insect pests that may not yet have a presence in Australia but in other areas of the world.

**Caterpillars** – including budworms, loopers, light-brown apple moth, rollers, cluster caterpillars, borers and cut-worms. Only the larval stages cause damage from feeding (chewing action) on the foliage of berry plants. There may be loss in leaf area, termination of the growing point or interference with flower and fruit set. The main form of control is the application of *Bacillus thuringiensis* (Bt) which is a bacteria found naturally in the soil and formulated for application by physical spraying. There are various strains or isolates available. The key to successful control is early intervention as the smaller larval forms are easier to kill.

**Spotted Wing Drosophila (SWD), Queensland Fruit Fly (QFF) and Mediterranean Fruit Fly (Medfly)** – all forms of fruit flies are a massive challenge to control because the eggs are laid directly in the fruit. The current options are focused on controlling the adult fruit fly through baits, lures and traps (refer Figure 23 and 24). SWD is becoming a severe issue globally as it is not affected by low temperatures. Eggs of SWD are laid into berry fruit that is still hanging on the plant at various ripening stages. It is virtually impossible to detect any sign of eggs laid in the fruit itself – only after visual signs of larval forms creating damage to the fruit is the impact revealed. A proactive approach is to use pheromone – based lures and traps to attract and control the adults. SWD has not been detected on Australian shores. It would appear that SWD does not tolerate high temperatures and humidity, commonly found in most states across Australia and which are, to a large extent, conditions associated with greenhouse berry production (Bruss, 2016).

***Figure 23: Make-shift trap for SWD in tunnel raspberries. (Source: N. Mann, Algarve, Portugal May 2016)***

***Figure 24: Red sticky trap to attract SWD in tunnel raspberries. (Source: N. Mann, Algarve, Portugal May 2016)***

## The main disease issues for the greenhouse berry industry

The adoption of substrate or hydroponic production methods has alleviated many issues originating from soil-borne diseases. However, poor substrate or hydroponic management practices may lead to an increase in susceptibility to plant pathogen incidence through incorrect watering, poor nutrition, ineffective sanitation or contaminated plant material. It would appear anecdotally that more success has been achieved with BCAs targeting insect pests than through BCAs controlling plant diseases based on the number and range of commercialised insect pest BCAs. The issue may well be underpinned by the fact that there is an abundance of diversity in the various strains of beneficial pathogens cultured for the specific disease to be controlled. The following plant diseases are more commonly encountered globally in greenhouse hydroponic berry production.

***Botrytis*** – this disease continues to wreak havoc in all forms of soft berry fruit production. It is prevalent under cool, moist conditions and may affect plants at different development stages, from cuttings to mature plants, including flowering and fruiting stages (refer Figure 25). Climate control is critical and is often achieved through greenhouse manipulation.

***Figure 25: Botrytis in glasshouse strawberries. (Source: N. Mann, Ireland May 2016)***

***Phytophthora, Fusarium, Pythium, Rhizoctonia* and other soil-borne fungal diseases**

Unless the plant material is infected prior to planting, these soil-borne fungal diseases are less invasive with correct cultural controls and good production practices, especially in substrate production using clean, Regeling Handelspotgronden (RHP) approved media.

**Powdery mildew**

This fungal disease mainly affects the leaves of berry plants created by diurnal fluctuations in temperature and humidity. The spores are spread through air movement in warmer, low humidity conditions and germinate in cooler, high humidity periods. This disease is debilitating to the photosynthetic potential of the plant, as leaves are covered on the surface with a white powdery substance.

## Biological chemicals for disease control

There are four major groups of biological products categorized as follows on the Australian Pesticides and Veterinary Medicines Authority (APVMA) website:

**Group 1:** biological chemicals (e.g. pheromones/semiochemicals, hormones and growth regulators, enzymes and vitamins)

**Group 2:** plant and other extracts (e.g. neem oil, plant extracts like pyrethrum)

**Group 3:** microbial agents (e.g. fungi, bacteria, viruses and protozoa)

**Group 4:** other living microorganisms (e.g. microscopic insects, plants and animals, genetically modified organisms)

There have been concerted efforts to develop and commercialise all of the above mentioned groups of biological products as evidenced by the major chemical manufacturing companies acquisition of smaller, niche-type biological manufacturing companies e.g. Bayer acquisition of AgraQuest, BASF acquisition of Becker Underwood, etc. who had initiated the biological trend.

The biological chemicals group products relative to crops have focused on plant health promotion through vigour and better resilience to potential pest and disease pathogen attack. For example, active ingredient laminarin is a polysaccharide of glucose found in brown algae. It has been proposed that algal extracts act as elicitors of plant defence mechanisms (Somssich, 1995). Elicitor effects are mediated by signalling pathways, among which salicylic acid (SA), jasmonic acid (JA) and ethylene, either alone or in a combination, play major roles in local and systemic induction of defence responses (Jones, 1996). These products are generally applied through the irrigation system or sprayed on the berry crop physically. They would normally be incorporated in a crop management program as a pre-emptive strategy for pathogen attack.

The microbial agents group is a reference to beneficial forms of fungi, bacteria, viruses and protozoa. According to Denise Manker, Bayer Biologics USA, beneficial bacteria such as *Bacillus subtilus* live on plant root surfaces and in the zone around the root system called the rhizosphere. Under suitable conditions, plants and bacteria in the rhizosphere may develop a mutually beneficial relationship through an active interface, where exudates produced from the plants roots are more effectively utilised by the beneficial bacteria and outcompete the pathogens by pre-colonisation of the rhizosphere (Manker, 2016). Robert Saville, plant pathologist at EMR added that the Systemic Active Resistance (SAR) level is also raised by the colonisation of beneficial microbes in the rhizosphere. Soil-borne pathogens have been contained under lower pressure incidence provided preventive inoculations, early on in the production phase, have taken place (Saville, Plant Pathologist at EMR, 2016).

*Bacillus pumilus* is another form of beneficial bacteria utilised as a microbial agent BCA to suppress fungal spores on plants. It forms a physical barrier between the plant leaf surface and the fungal spores before further colonising the individual fungal spores (AgraQuest, 2006). *Apelomyces quisqualis* is a beneficial fungus that parasitizes hyphae, conidiophores and cleistotheica of powdery mildew (Biogard, 2016).

## Biological chemicals for insect pest control

Biological chemicals from all four major groups of biological products may be selected as options to control insect pests. There are variations in the mode of action, but provide the greenhouse berry grower with bio-rational alternatives to mitigate disruptions to predatory and parasitoid BCAs that may have been released previously into the berry crop.

Pheromones are a class of semiochemicals that insects (in this case) use for various forms of communication with individuals of the same species. There are three main uses of pheromones in the integrated pest management of insects. Monitoring of populations of insect pests to determine presence at an early stage, which may then warrant an early intervention control based on pest numbers is the first use. This method is particularly important for early detection of exotic pest incursions such as Spotted Wing Drosophila (SWD) in berry crops. The second use is for mass trapping of regular, anticipated pest incursions such as light-brown apple moth. The third use is to disrupt mating patterns of insect pests (Nevada, 2012).

Plant and other extracts are usually oil based plant extracts and naturally produced chemical compounds, such as pyrethrum. The oil-type products such as neem oil, (with the active ingredient Azidarachtin) have a smothering action due to the oil coating the insect's body and also reducing the hormone responsible for the moulting process. Most oil-based products have low toxicity levels and short residual period and therefore offer little disruption to predatory and parasitoids BCAs (University of Connecticut, 2011). Pyrethrum on the other hand is a toxic product with broad-spectrum action. It also has a short residual value and therefore may be a favoured product to use in spot-spraying, or in high pest pressure related periods to get an instant knock-down result.

Microbial agent formulations directed at controlling insect pests are regarded as entomopathogenic. Entomopathogenic Fungi (EMFs) are more commonly used in greenhouse berry crops. *Beauvaria bassiana* has been utilized successfully for the control of various insect pests as an EMF in North America on berry crops. It may be applied as a conventional spray or via a modern, innovative technique called entomovectoring. Essentially, the EMF spores make contact with the pest insect's cuticle and germinate to colonise and ultimately penetrate the cuticle via enzymes produced by the spore colony. Death of the pest insect eventuates as the EMF spores rapidly multiply within the host body cavity (Bioworks, 2016).

Within the other living organism group of biological products available for greenhouse berry growers, entomopathogenic nematodes (EN) have been used to gain satisfactory results. EN's are microscopic eelworms found in soil and water. There are formulations for application via the irrigation system to control soil-dwelling insect pests such a Fungus gnat, or via conventional spraying equipment to control various caterpillar species or weevil types. EN's in the larval stage enter through the pest insects body openings or the skin and ultimately release bacteria in the host with death occurring through septicaemia.

## Mycorrhizae under greenhouse hydroponic berry production systems

Mycorrhizae form a symbiotic association between roots of plants and the fungus itself. *Arbuscular mycorrhizal* fungi (AMF) are asexual organisms with hyphae that penetrate plant roots to form arbuscles and spores. They assist host plants in nutrient uptake (primarily N, P and Zn) and provide protection from both abiotic and biotic stresses. AMF have been used extensively in traditional soil-based strawberry and raspberry production, but only recently in substrate or hydroponic production of these fruit. A noticeable reduction in colonisation of plant roots of AMF in substrate compared with soils did not cause any adverse impact on a strawberry trial at EMR, as there was an average 10-20% increase in Class 1 fruit using commercial fertigation regimes and also resulted in a 40% reduction in water use (Robinson-Boyer, 2016).

# Chapter 6: Entomovectoring

Entomovectoring is an innovative delivery technology for biocontrol agents. Extensive research and trial work has led to the commercialisation of pollinator biocontrol vector technology, known as entomovectoring. The basis of this technology involves harnessing a pollinator to vector a form of microbial biocontrol and depositing this microbial formulation on the flowers of the crop being pollinated. Bumble bees have been widely used for successful pollination in greenhouse crops (excluding Australia), including berries. Through retrofitting an inoculum dispenser to a typical bumble bee hive, the microbial powder formulation is spread within the dispenser to ensure that on exiting the hive, the bumble bee workers will walk through the product which will attach to their hairy legs and body. As the bumble bee lands on the flowers of the berry crop in search of pollen, the microbial powder formulation is deposited onto these flowers through the brushing action of the bumble bee on the floral parts. The microbial formulation then begins to take control of its targeted host. A greater percentage of the microbial bio-controls are EMF's for controlling insect pests or microbial agents targeting plant diseases such as *Botrytis sp*. There are significant benefits to greenhouse berry growers through this technology, but there are also noticeable limitations. Bumble bees are not permitted on mainland Australia and therefore the author was seeking to identify the opportunity of using the European honey bee as an alternative vector, which is used extensively for pollination of greenhouse tunnel berry crops within Australia.

| ADVANTAGES | LIMITATIONS |
|---|---|
| Reduction of synthetic pesticide application | Sensitivity of BCAs to environmental conditions |
| Better delivery of BCA to target location (e.g. flower) | Carriers for BCAs variable in vector acquisition |
| Frequent and repeated dissemination of BCA covering varying developmental stages | Dispenser lay-out and efficiency for vector |
| Environmental and ecological benefits | Potential dissemination on non-target sites |
| No unnecessary wetting of crop | Sub-lethal concentrations of BCAs may influence changes to physiology and behaviour of vector |
| Option of vectors | Limited number of approved BCAs for entomovectoring |
| | Uneven dispersal of BCA throughout the target crop with higher concentration closer to the hive and much less further from the dispenser. |

***Table 1: Advantages and Limitations of Entomovectoring*** (Mommaerts & Smagghe, 2011)**.**

| **Bumble Bees** | **Honey Bees** |
|---|---|
| More tolerant of greenhouse conditions | Difficulty in navigation in enclosed greenhouses |
| Remain in close proximity of hive | High frequency of visits to flowers and good cross-pollination |
| Fewer bumble bees per hive | Visit alternative crops in surrounding areas which disperses BCA to non-specific target |
| Active in a range of weather conditions including extremes of temperature, humidity and light | Always search for most lucrative nectar or pollen source which may not always be the target crop |
| Not safe for Bt. vectoring | Require multi-floral diversity |
| | Safe for Bt. vectoring |

***Table 2: Comparing Bumble Bees and Honey Bees as Vectors for Entomovectoring* (Steen, 2015).**

# Chapter 7: Conclusion

Food safety and the limited number of chemical controls available for greenhouse hydroponic berry production are the underlying motivation for primary producers to adopt IPM strategies. However, biological control without some form of chemical control is almost impossible – but the requirement is to use 'soft' bio-rational type products. It is also not about total control of pests, but rather effective management of the pests. The timing and method of release of BCAs is critical to the success of pest control and this is achieved through regular monitoring and scouting to enable early detection of pest presence (Goodwin, Biocontrol is good agricultural business, 2009).

Individual BCAs work well within a specific range of conditions. The diverse climatic zones in Australia make it particularly challenging for a limited range of commercially available BCAs to operate and achieve success under the various climatic zones. Physical controls to modify the environment through protective cropping structures in the berry industry have significantly assisted in the overall success of disease control. "*Due to the complex ecological processes involved, success in biocontrol of plant diseases in field crops has been limited; most successes have been achieved in greenhouses"* (Paulitz, 2001).

The registered chemical control products for greenhouse berry crops in Australia cater for a range of commonly occurring pest issues, with options to rotate chemical groups as a pesticide resistance management strategy. The APVMA ensures that each chemical control product satisfies a series of relevant criterion, least of which concerns the safe MRL of the product relative to the specific berry crop. It is imperative that there are regulatory mechanisms in place to assure consumers of berry fruit that these products are safe to feed their families.

The pricing structure of BCA products must be competitive with conventionally produced synthetic chemicals. This will assist in convincing the primary producer to adopt prophylactic releases in large numbers of arthropod BCAs when pest pressure is low (Labuschagne, 2015). A combined application of microbial formulations and elicitors in both seven and fourteen day spray programs is considered a proactive approach to soil-borne pathogen suppression in hydroponic systems (Berrie, 2016) Products of biological chemical classification have low to zero MRL's and provide the opportunity to strengthen and maximise plant defence mechanisms.

SWD appears to be the key pest insect demanding attention for control strategies in the Northern Hemisphere. Significant research projects are being undertaken in an attempt to contain this elusive and now notorious fruit fly. An assortment of pheromone-based lures and traps are providing limited control. SWD has inadvertently lead to growers cleaning up reject and damaged fruit within greenhouse berry crops and this cultural practice has led to a reduction in other plant diseases like *Botrytis sp*. (Saville, 2016).

The synergistic association between mycorrhizal fungi and plant roots provides a real opportunity for hydroponic berry producers to benefit from this interaction. Plants secrete up to 40% of photosynthetically fixed carbon into the rhizosphere through root exudates (Bais, Weir, Perry, Gilroy, & Vivanco, 2006). These exudates, in the form of carbohydrates, are needed for fungal growth, whilst the mycorrhizal fungi increase the root surface area. Benefits for the berry crops include a greater potential for reduced inputs (water, fertilizer, chemicals) and optimisation of the available resources. *Arbuscular mycorrhizae* are the most prevalent endomycorrhizal fungi and co-exist with strawberries, raspberries and blackberries. *Ericoid mycorrhizae* are less common endomycorrhizal fungi and are specific to Ericaceous plants such as blueberries.

Many current berry production systems rely heavily on repeated applications of chemical pesticides in order to reduce plant disease problems with well-known negative side effects. One of the worst global, economically relevant problems is grey mould (*Botrytis cinerea*). It is the most common fruit rotting pathogen and one of the most important biotic threats for the berry industry. A control concept developed for *Botrytis* control combines two key ecosystem services, biological control and pollination, via entomovectoring where pollinating and flower visiting insects are utilised to disseminate beneficial microbial formulations to target the flowering phase of fruiting crops (Boecking & Kreipe, 2012).

# Chapter 8: Recommendations

With the demand for berry fruit around the globe soaring, growers are adopting protected cropping and substrate production to increase yields and minimise crop losses. IPM must be considered due to the nature of berries being a soft fruit with an edible skin leaving no option for breaching food and health safety standards.

Biological control is not about the total control or eradication of pest and disease problems, but rather the effective management of these two elements.

The timing and method of release of BCAs is crucial to the successful adoption of this control strategy. Early, prophylactic releases of BCAs achieve greater results than a delayed release option when pest and disease incursions are at elevated levels and difficult to overcome.

The development of alternate biological control methods are not necessarily keeping up with the revoking of certain conventional chemicals. It is therefore imperative to consider the cultural and physical control options in combination with biological control methods.

Chemical controls should be regarded and used as a support tool as opposed to a primary tool. Consideration should be granted to the substitution of broad-spectrum 'hard' chemicals for host-specific bio-rational type products which are more efficacious and generally less toxic and therefore 'soft' pesticides.

Australian greenhouse hydroponic berry growers have a suite of arthropod BCAs available for crop protection but the biological chemical options remain limited for pest and disease control. However, opportunities to further engage in plant strengtheners and growth promoting biofertilizers present great potential.

# Glossary

**Auto-dissemination -** to automatically spread or disperse beneficials

**Beneficial(s) -** organisms (as ladybugs, lacewings, and bacteria) that feed on or parasitize pests of crops, gardens or turf. (Mirriam-Webster, Mirriam-Webster, 2016)

**Bio-fertilizer -** is a substance which contains living microorganisms which, when applied to seeds, plant surfaces, or soil, colonizes the rhizosphere or the interior of the plant and promotes growth by increasing the supply or availability of primary nutrients to the host plant. (Wikipediea, 2016)

**Bio-fungicides -** are microorganisms (microbial pesticides) and naturally occurring substances that control diseases (biochemical pesticides) that are approved for organic production. (Google, 2016)

**Bio-insecticide -** Any naturally-occurring (rather than synthetic) insecticide

having specific activity against one or more insects. (Dictionary Y. , Your Dictionary, 2016)

**Biologicals or Biological Control -** is a method of controlling pests such as insects, mites, weeds and plant diseases using other organisms. It relies on predation, parasitism, herbivory, or other natural mechanisms, but typically also involves an active human management role. It can be an important component of integrated pest management (IPM) programs. (Wikipedia Biological Pest Control, n.d.)

**Bio-pesticides -** a pesticide consisting of naturally occurring or genetically engineered microorganisms (as bacteria) (Mirriam-Webster, Mirriam-Webster, 2016)

**Bio-stimulants -** A plant bio-stimulant is any substance or microorganism applied to plants with the aim to enhance nutrition efficiency, abiotic stress tolerance and/or crop quality traits, regardless of its nutrients content. By extension, plant bio-stimulants also designate commercial products containing mixtures of such substances and/or microorganisms. (Jardin, 2015)

**Biological Control Agents -** is the term referred to the natural enemies (including predators, parasitoids and pathogens) used to reduce invasive species populations (Consortium, 2016).

**Ellicitors -** in plant biology are extrinsic, or foreign, molecules often associated with plant pests, diseases or synergistic organisms. Elicitor molecules can attach to special receptor proteins located on plant cell membranes. These receptors are able to recognise the molecular pattern of elicitors and trigger intracellular defence signalling via the Octadecanoid pathway. This response results in the enhanced synthesis of metabolites which reduce damage and increase resistance to pest, disease or environmental stress. This is an immune response known as pattern triggered immunity or PTI. PTI is effective against necrotropic microorganisms (Wikipedia, Wikipedia, 2016).

**Maximum Residue Limits –** this is maximum level of approved chemical residue allowed on the fruit at the time of harvest and subsequent sale and is set by the APVMA and complies with the Food Safety Standard.

**Pathogen -** any disease producing agent, especially a virus, bacterium, or other microorganism (Dictionary, 2016).

**Parasitoid –** insects that feed on the body of another insect or arthropod during the larval stage of their life cycle. The host organism will die as a result. When the parasitoid completes its life cycle, it becomes a free-living insect, no longer dependent on the host. (Insects About, 2016)

**Residue -** a substance that remains on produce after a process such as spraying or evaporation has occurred, usually referring to a pesticide or herbicide application.

**Re-Entry Interval –** is the minimum amount of time that must pass between the time a pesticide was applied to an area or crop and the time that people can go into that area without protective clothing or equipment (Canadian Centre for Occupational Health and Safety, 2016).

**Withholding Period –** withholding periods (WHPs) are used to ensure compliance with domestic maximum residue limits (MRLs) and can be defined as the minimum period of time that must lapse between the last application of an agricultural chemical product, and the ‘use’/consumption of the agricultural produce to which the chemical was applied (Agriculture Victoria, 2016).

**Vernalisation -** is the induction of a plant's flowering process by exposure to the prolonged cold of winter, or by an artificial equivalent. After vernalisation, plants have acquired the ability to flower, but they may require additional seasonal cues or weeks of growth before they will actually flower (Wikipedia, Vernalisation, 2016).

**Volatiles -** more commonly known as Green leaf volatiles (commonly abbreviated as GLV) is a volatile organic compound term to describe the variety of chemicals that are released when plants suffer tissue damage. Specifically, it refers to aldehydes, esters, and alcohols of 6-carbon compounds released after wounding. Some of these chemicals act as signalling compounds between either plants of the same species, of other species or even vastly different lifeforms like insects. Some of these chemicals act essentially as plant pheromones.

The smell of a freshly mowed lawn is best known to humans, but for other forms of life GLV have a far less trivial function, mostly as a warning signal of oncoming causes of tissue damage, but also as a form of inter-species signalling - for example, to attract insects that prey on caterpillars that are consuming the plant (Wikipedia, Green Leaf Volatiles, 2016).

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# Plain English Compendium Summary

| | |
|---|---|
| **Project Title:** | **IPM Strategies for Greenhouse Hydroponic Production of Berry Crops** |
| Project No. | 1520 |
| Scholar: | Wade Mann |
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| **Objectives** | • To explore and assess global best practice IPM strategies for greenhouse hydroponic berry crops.<br>• To identify emerging and innovative technologies associated with biocontrol agents (BCAs) available for commercial application whilst maintaining overall quality of soft fruit.<br>• To consider and gauge the feasibility of adopting entomovectoring in a commercial greenhouse environment for berry production.<br>• To make practical and commercially viable recommendations to growers adopting IPM in intensive greenhouse hydroponic production of berries within Australia. |
| **Background** | To seek a balanced perspective across growers, researchers and biological control agent suppliers of IPM options and applications. |
| **Research** | Comprehensive meetings with global leaders in research centres, and universities conducting trials on biological controls and products and including commercial biological suppliers promoting their products. Also interviewed were a range of commercial growers, from owner/operator small scale berry production to multi-national corporation berry production supply companies. |
| **Outcomes** | Australian greenhouse hydroponic berry growers have a range of beneficial BCAs available for crop protection but the biological chemical options are limited at present. Opportunities to further engage in plant growth promoters and biofertilizers present the greatest prospect in pest control in the near future. |