A Comprehensive Study of the Australian Commercial Insectary Industry and its Implications for Augmentative Biological Control

Mahmuda Begum

A thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

Faculty of Agriculture and Environment

The University of Sydney

April 2016

Statement of originality

I hereby declare that this thesis is the product of my own work and is an original work which has not been submitted either in full or in part for any other degree or diploma at The University of Sydney or any other educational institution. To the best of my knowledge it does not contain any materials previously published or written by another person, except where due acknowledgement is made in the thesis.

Mahmuda Begum

April 2016

Abstract

The Australian commercial insectary industry produces biological control agents (predator, parasitoid and nematode BCAs) to control pests. The use of commercial BCAs in Australia is being hindered by a range of factors but to date no study has been done on the Australian insectary industry. This study constitutes the first report about this industry.

This study reviews the literature on insectary industries, integrated pest management (IPM), augmentative biological control (ABC) and the commercial biological control agents (commercial BCAs) and their adoption by the growers in the global context with special emphasis on Australia. A mixed method design was used to collect both qualitative and quantitative data. During 2011–2013 semi-structured interviews (27) were conducted to identify the perspectives of insectary owners (9), citrus pest management researchers (9) and citrus growers (9). A national survey of citrus growers (a case study) was also conducted. Following a Participatory Action Research (PAR) framework, research results were sent to the participants (who had been previously interviewed) to seek further input into the development of recommendations.

The Australian insectary industry started with citrus pest management in the 1970s. Over 40 years the industry has expanded from one company and one commercial BCA to five companies and 36 commercial BCAs in 2014. This expansion was largely in response to one pest (two spotted spider mite) developing resistance to multiple insecticides in Australia. After this initial (1991–2001) expansion the industry has stopped growing. Currently, two insectaries produce most of the commercial BCAs. Most of the companies

are poorly capitalised with estimated gross sales well below AUD$10 million for the 2010–2011 financial year.

It is clear that this industry faces many barriers. The size of the domestic market for commercial BCAs is very small and there is no export market. The industry is primarily horticulture based in Australia. Only a few organic growers use commercial BCAs. The cost of establishing a new insectary is very high. The cost of developing a new commercial BCA is also very high and by itself this industry does not have the resources to do this. Biosecurity is an issue for export and import of commercial BCAs. The industry is dependent on long distance transport. It and its clients are both based in rural areas and Australia is a very large country.

The citrus pest management researchers believed that different factors such as climate, regional impacts, market destination, selective insecticides, insecticide resistance, effectiveness of the commercial BCAs, crop types, different cropping systems, developmental time between the pests and beneficial insects and growers' attitude are all important factors that influenced growers to adopt commercial BCAs.

Citrus growers' interviews and survey results showed that economic factors have a major impact on the commercial BCAs' adoption by citrus growers. Large farm owners were more likely to add commercial BCAs into their IPM program because they have more employees and often use a consultant and received better profit than small farm owners. Growers pointed out that adoption of commercial BCA is complicated, information intensive and needs a consultant. The complexity of the adoption of commercial BCAs is the main reason that deterred small farm owners. Growers ruled out insecticide resistance and insecticide withdrawal as driving factors for the adoption of commercial BCAs. Growers did not receive any support from the government except information.

The factors were identified by insectary owners, researchers and citrus growers that uncovered the fundamental barriers and drivers of this industry. They developed the joint construction of the critical components of the commercial BCA adoption system and the industry expansion.

Patents (rearing methods and pest control techniques because free living organisms cannot be patented) are essential for expansion of the Australian insectary industry. In Australia, only nematode commercial BCAs are patent protected but the lack of patents for the remaining commercial BCAs makes this industry an unprotected business. The insectary owners keep their rearing methods secret and were cautious about training people, because of commercial confidentiality. Insectary owners believed that the patenting process is expensive and laborious and needs experience and time. This constrained commercialisation and integration of commercial BCAs into crop protection. The insectary owners need to change their attitude towards it, train up more people for technical support to growers and avoid direct competition. They can give or sell licenses to the secondary insectary companies. They need collaboration with other research organisations, within their own industry, and with different crop industries. Collaboration is also essential for the actual implementation of commercial BCAs. Survey results showed that small farm owners need technical support to incorporate commercial BCAs into their pest management program. This industry needs to develop technical support mobile phone apps and insect identification and monitoring 'flash cards'(flash cards are photographic and descriptive of the various life stages and monitoring tips). They can give technical support through Skype (or equivalent app) and could use a 'model grower' as an advertisement. More species of commercial BCAs are necessary to manage all of the pests in a particular crop, for instance citrus crops. This industry needs to focus on organic farmers and encourage their uptake of commercial BCAs.

The Australasian Biological Control Association Inc. needs to join with other related associations to form a lobby group to convince government to support this industry. Like many European countries a capital grant from the government is required to build a hi-tech production facility, research support and/or tax incentives to growers that use IPM and commercial BCAs. It will help the massive expansion of this industry and without this support this industry cannot be expanded as it is expected. A wider education about IPM is required. Like the IFP (Integrated Fruit Production) logo in many European countries, the introduction of an IPM logo for fresh produce to promote fresh produces grown using IPM is needed. This will encourage consumers to ask supermarkets for products displaying appropriate labels or logo as well as inspire consumers to know more about IPM. This industry can establish or contact local fruit and vegetables shops to sell IPM produce and encourage them to play a video that will show fruit and vegetables grown using IPM. The insectary companies need to establish or contact retail agents in every state or cropping area to facilitate growers to gain easy access to the source of commercial BCAs. Pest management consultants and extension officers require some education about IPM or commercial BCAs because they are the agents of change for the growers' attitude.

The Australian insectary owners, policy makers, IPM researchers and practitioners need to take these recommendations into consideration to expand this industry. Several areas such as promotion of commercial BCAs, selective insecticide use in IPM, commercial BCA use in the organic cropping system, entomology skill shortage and protectiveness warrant further research to better understand the adoption of commercial BCAs. Further research on growers and consumer attitudes will help to implement commercial BCAs and enhance the expansion of the Australian commercial insectary industry.

Acknowledgements

It is a great pleasure to acknowledge so many people and organisations. This thesis would not have been possible without their encouragement and support during my PhD research.

Firstly I would like to thank my principal supervisor Dr Sarah Mansfield for her continual guidance, encouragement, endless advice and lots of good ideas during this work. Thanks for spending her time and effort in reviewing this thesis. Thanks are also extended to my associate supervisor Dr Peter Ampt for providing a social research concept and invaluable suggestions throughout this study; also thanks for reviewing the various drafts of this thesis. I extend my sincere thanks to Dr Edith Lees for her encouragement, availability and invaluable suggestions during the writing of this thesis. Thanks are also extended for her time and effort to editing this thesis.

My sincere thanks are extended to the Australian insectary owners, researchers and citrus growers who participated in this project. I truly could not have completed this thesis without their cooperation and participation in this research. Thanks are also extended to those pest management consultants, insectary owners and citrus growers who circulated surveys to citrus growers.

I would like to acknowledge Citrus Australia Ltd. for circulating surveys through their email database. Thanks are also extended to The Murray Valley Citrus for publishing the survey invitation. Special thanks to Katie Fisher (Managing Editor AgriHort Communications Pty Ltd) for publishing a survey invitation letter in Australian Citrus News (Volume 89 June/July 2012). Thanks are also extended to her for the distribution of the survey invitation handout with the Australian Citrus News (Volume 90, August/ September 2012). I am grateful to Mr Kym Thiel (Value chain coordinator-Citrus Australia Ltd) for his help and cooperation throughout the data collection of this project.

I would like to thank the University of Sydney for the Australian Postgraduate Award (APA) and the Faculty of Agriculture and Environment for the Top-Up scholarship. I am also grateful to the University of Sydney for the Postgraduate Research Support Scheme (PRSS) for supporting me to participate in the Australian Entomological Society Conferences in Western Australia (Perth), New Zealand (Christchurch) and Tasmania (Hobart). I would also like to thank the University of Sydney for supporting me to travel to different States of Australia for data collections. I would like to acknowledge all the staff members from the Faculty of Agriculture and Environment for their cooperation and help during this study.

I am grateful to my friends, fellow postgraduates and staff for numerous stimulating discussions and creating a warm environment with great happiness during my study in the university. Special thanks to Dr Lai Fan Poon, Mulatua Metaferia, and Jingwen Cai, for their friendship and support. Thanks to Damien (undergraduate student of this Faculty) for volunteering his time to collect surveys from the Citrus Australia's workshops in the Riverland (Waikerie,) and Sunraysia (Dareton).

Finally, my heartfelt gratitude goes to my mother and late father. I am also grateful to my brothers and sisters for their help and inspiration throughout this study.

Table of contents

List of tables

List of figures

List of boxes

Chapter 1: Introduction

This study investigates the Australian commercial insectary industry which produces biological control agents for augmentative biological control. Augmentative biological control involves one to several releases of commercial biological control agents (commercial BCAs) to suppress a pest during the course of a season or a crop's production cycle (Luck and Forster, 2003). Augmentative biological control is one of the strategies used in Integrated Pest Management (IPM). Integrated pest management is a recognised pest management approach which combines and integrates different strategies of pest control (Maredia, 2003). Both open field and greenhouse crops are treated with commercial BCAs around the world.

1.1 Commercial insectaries

The first use of augmentative biological control agents started sometime between 1913 and 1917 with citrus pests in Southern California (Dietrick, 1981). The development of insectaries started with citrus pest management in Southern California where many insectaries were organised by the regional government (Luck and Forster, 2003). Everett J. Dietrick was the pioneer of the commercial insectary industry and started the first insectary in his garage in Riverside, California, in 1950 (Dietrick, 1981). In the 1950s, the introduction of synthetic pesticides into the pest management system caused the government organised insectaries to be closed. Only the private and grower-owned insectaries remained operational (Graebner et al., 1984). Historically, the United Kingdom was the first country where augmentative biological control agents were seen as a great success in the 1920s where *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae) was used to control greenhouse pest whitefly, *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae) (van Roermund et al., 1997).

In Australia, a few citrus growers at Merbein, in Victoria in the Sunraysia district, started to use augmentative biological control agents in 1944. Biological Services Inc., Australia's first commercial insectary, started in 1971 providing commercial BCAs for pest management in citrus crops at Loxton in South Australia (Furness et al., 1983).

1.2 Current status of commercial insectaries

There were an estimated 530 commercial insectary companies producing about 170 biological control agents around the world. There were about 30 larger (more than 10 people employed) and 500 smaller (2–10 people employed) companies (van Lenteren, 2012). Most of the commercial insectary companies primarily rear predators (eg, predatory beetles, mites etc.) and parasitoids (eg, parasitoid wasps, flies etc.). Only a few companies produce entomopathogenic nematodes. The predators, parasitoids and nematodes together are called macro-biological control agents. Micro-biological control agents (fungi, viruses, protozoa and bacteria) are produced mainly by chemical companies. This study discusses only macro-biological control agents not micro-biological control agents.

Worldwide, there is evidence that the commercial BCAs' market is increasing especially in Europe and USA because of greenhouse expansion and rules and regulations increasing consumers' awareness about food safety etc. It has been reported that in 1995 it was worth US$40 million and by 2003 it was worth US$190 million for global commercial BCAs (Office of Technology Assessment, 1995; Guillon, 2004). In North America, surveys (2004–2006) estimated gross annual value of US$25–30 million at the wholesale level (Warner and Getz, 2008). European commercial BCAs' market value became more than US$30 million by 1997 (Hajek, 2004). Pilkington et al. (2010) reported that the commercial BCAs' market is increasing, especially in Spain where it reached 30 million Euros (about US$41 million). Currently this value might be higher than the author understands but there is no up- to-date report available.

The commercial BCAs are apparently becoming more widely accepted by growers. Many researchers claim that the growing number of commercial BCAs and suppliers of commercial BCAs indicate that the practice of augmentative biological control is expanding (Parrella et al., 1992; van Lenteren, 2003a; Cock et al., 2010; Pilkington et al., 2010). For example, the increased demand from exporters for commercial BCAs in South Africa and Kenya has resulted in the establishment of new companies, BCP Ltd and Dudutech and in Cuba the government helped to establish local insectaries (Cherry and Gwynn, 2007). There are several reasons given for this expansion, such as the development of insect resistance to pesticides, increased consumer awareness about the impact of pesticides on the environment and human health, to fulfil export market regulation and finally the changes in funding policy towards pesticide use (Cherry and Gwynn, 2007).

While many researchers claim that the biologically based pest control market has expanded rapidly (Office of Technology Assessment, 1995; Guillon, 2004; Cock et al., 2010), the industry has critics. Some argue that commercial BCAs are less effective than chemical control, are effective against only a small group of pest species, have certain ecological limitations, and are more expensive than pesticides. They claim that it is for these reasons that augmentative biological control has not fulfilled its potential (Collier and Steenwyk, 2004; Yano, 2004).

Integration (harmonisation) of technical, scientific, agricultural, economic and social factors is required to make commercial BCAs successful (van Lenteren and Bueno, 2003; Warner and Getz, 2008). Moreover, the extent of growers' uptake of commercial BCAs is largely influenced by the strengths and weaknesses of the commercial insectary companies (Warner and Getz, 2008). Therefore, in analysing the sustainability of augmentative biological control as a pest management strategy it is essential to investigate the commercial insectary industry.

1.3 The problem in Australia

In Australia, the first commercial insectary started in the 1970s, and after four decades seven commercial insectaries produce 31 species of biological control agents including insects, mites and entomopathogenic nematodes (van Lenteren, 2012). Some new commercial BCAs are under development (www.goodbugs.org.au). The Australian and the New Zealander commercial insectary owners established the Australasian Biological Control Association Inc. in 1992. It promotes collaboration between producers and the sharing of knowledge and experience gained from rearing these organisms and using them for pest control. It developed a website which has links with each insectary company (Llewellyn et al., 2002).

Seven insectary companies were commercially operating in 2011 but the number has been reduced further and only five companies are commercially operating in 2014 (www.goodbugs.org.au). In terms of the first insectary establishment, the Australian insectary industry (1971) is far behind the European industry that was founded in 1968. Currently, approximately 30 large insectary companies commercially produce biological control agents worldwide and two third of them located in the Europe (Tracy, 2014). The European insectary industry exports commercial BCAs worldwide whereas the Australian industry is entirely domestic market based. Perhaps this is one of the reasons for this industry expansion. In terms of agricultural land uses the Australian commercial insectary industry is not expanding to the same extent as in other countries such as Europe. Compared with the agricultural land use in Europe (4748363 km2 in 2007) is not much larger than Australia (4254490 km2 in 2007) (www.en.worldstat.info/Europe/Land; ABS, 2012). What are the barriers and how have they affected the expansion of the commercial insectary industry in Australia? To understand this complex situation the Australian insectary industry needs to be viewed in the broader context of horticultural crop protection, including from the perspective of the insectary industry, the researchers and the current and potential clients of that industry involved. The different factors which affect the expansion of the Australian commercial insectary industry must be identified but to date no study has been done on the Australian industry. In the USA, Cranshaw et al. (1996) reviewed the 1994 pricing and marketing by biological control suppliers and van Lenteren et al. (1997) did the same for Europe. There is no such review or information about pricing for commercial BCAs available for Australian producers. Further, in Australia, no information is available for the total annual sales of commercial BCAs.

It is clear that there are barriers that are preventing the expansion of the Australian insectary industry and it may be assumed that the Australian commercial insectary industry is still in its infancy compared with the European and American insectary industries.

1.4 Research aim

The overall research aim is to conduct a comprehensive study of the Australian commercial insectary industry and its implications for augmentative biological control.

The specific Objectives of this Research were:

1. To identify the factors which may hinder the Australian commercial insectary industry's growth or be necessary for its expansion from the perspectives of the insectary owners?
2. To identify the key barriers to augmentative biological control (commercial BCAs) and the different factors that influence these barriers from the perspective of the researchers involved.
3. To examine the viability of the commercial insectary industry in Australia with particular reference to its use in the citrus industry and identify citrus growers' attitude towards the use of commercial BCAs.
4. To integrate Objectives 1–3 to determine the economic, social and political factors that impact on the Australian commercial insectary industry and identify opportunities for this industry and public policy to create the environment to assist the industry.

Augmentative biological control or use of commercial BCAs in Australia is being hindered by a range of factors and as a consequence the Australian commercial insectary industry is not expanding. These factors can be identified by industry participants (insectary owners), researchers (who are doing research on citrus pest management) and citrus growers.

Interviews with insectary owners explored their experience, belief, their perception about the Australian commercial insectary industry and its lack of expansion. This addressed the specific Objective 1. The citrus pest management researchers' perception about the adoption of commercial BCAs by growers addressed the Objective 2. This research is focused on citrus because this was the first crop where commercial BCAs were used commercially to control pest insects in Australia. The citrus growers' survey will identify the role of growers in the adoption of commercial BCAs which is largely influenced by the growers' attitudes. Several factors (participants' information or demographics, economic, farm practices, growers' perceptions, technological and institutional factors) may impact upon the decision process for adoption. This addressed the Objective 3. Objective 4 is the integration of Objectives 1–3 so this addressed the overall aim of this research.

The results will assist in the development of recommendations for the Australian commercial insectary industry as well as augmentative biological control researchers/practitioners to increase adoption of commercial BCAs in Australia. Involving the industry owners, citrus pest management researchers and citrus growers in the survey process will increase the utility of study recommendations.

1.5 Structure of the thesis

The thesis structure is below-

Chapter 2 is a literature review which provides a brief description of integrated pest management (IPM), biological control, and augmentative biological control. This chapter also describes the commercial BCAs and their implementation in the global context with special emphasis on Australia. It provides the historical description of the commercial insectary industry in the global context that outlines the Australian commercial insectary industry's current situation and reveals the Australian insectary is not expanding to the same extent as in other countries.

Chapter 3 addresses the research design, theoretical framework and social research methodologies that have been applied in this research. The rationales for using ethnographic participatory action research framework and mixed methods data collection approaches are explained. The chapter provides the sampling methods and how the semi-structured in-depth interviews were conducted with the Australian insectary owners, citrus pest management researchers and citrus growers. It explains how national surveys were conducted with citrus growers as well as data analysis strategies for both interviews and survey. It also explains researchers' biases and steps that have been taken to overcome biases and ensure research validity.

Chapter 4 reports the results of research pertaining to the specific Objective 1 on the barriers which may hinder the insectary industry's growth or be necessary for its expansion. Insectary owners are the key informants of this industry and this chapter explored their in-depth perspective which uncovered the fundamental barriers in production, marketing and distribution of commercial BCAs in Australia. This chapter also explores the factors that may be necessary for the expansion of this industry.

Chapter 5 outlines the finding from the researchers' interviews which describes how researchers perceived the adoption of commercial BCAs by growers and its implication for the augmentative biological control. This addresses the specific Objective 2. The chapter also reports the researchers' viewpoint about factors that are hindering or may be necessary for the expansion of the Australian commercial insectary industry and the implementation of commercial BCAs in Australia.

Chapter 6 provides the findings from the Australian citrus growers' interviews and the national survey of citrus growers. It specifically relates to the Australian growers' attitudes towards the use of commercial BCAs. This addresses the specific Objective 3. The chapter explores the in-depth perspective of the citrus growers' role in the adoption of the commercial BCAs through interviews and the national quantitative survey. The chapter explores how different factors influence citrus growers' attitudes towards the use of commercial BCAs in their pest management systems.

Chapter 7 provides the general discussion. The chapter describes the key findings from the specific Objectives 1–3 (Chapters 4–6). The chapter also provides discussion about emerging issues and contribution to knowledge as well as future research direction in this area. A summary results report was prepared from this analysis for the interviewees, the Australian insectary owners, citrus pest management researchers and citrus growers.

Chapter 8 provides the feedback from the interviewees. The chapter addresses the Objective 4 and describes how feedback was collected from the interviewees and then analysed. The chapter identifies the critical interventions needed for expansion of the Australian insectary industry. Finally, the chapter provides recommendations and the overall conclusions of the thesis.

Chapter 2: Literature review

Augmentative biological control (ABC) is an approach to the introduction of natural enemies into an agro-ecosystem which is one of the components of an Integrated Pest Management (IPM) strategy. Without discussing IPM and biological control first, ABC becomes meaningless because ABC is not a stand-alone approach.

2.1 Integrated pest management

In 1972 Integrated Pest Management, and its acronym IPM, was incorporated for the first time in English literature and widely accepted by the scientific community. The idea of integrated control first appeared in a paper by Hoskins et al., (1939) (Smith, 1974). Many authors cited that integrated control was well established towards the end of 1960s (Smith R.F. and Huffaker, 1973; Smith, 1974). In 1961 Australian ecologists first proposed a concept of "Pest Management" that became well recognised in the USA (Geier and Clark, 1961). Finally the union of the two concepts (integrated control and pest management) produced "Integrated Pest Management" (IPM) (Bajwa and Kogan, 2002). It took over ten years to develop a scientific basis for IPM since integrated control was first defined (Stern et al., 1959). Fitt and Wilson (2012) reported that it took over 50 years to develop a framework (a basic structure underlying a concept of IPM) for today's IPM.

Today IPM is the established model for crop protection worldwide from both an economic and environmental point of view. Many national, regional and international programs contribute to a favourable environment for IPM. In the mid-1990s the global IPM facility was established with the co-sponsorship of the Food and Agriculture

Organization (FAO), the UN Development Programme (UNDP) and the World Bank. Worldwide coordinating, consulting, advising and promoting of IPM are the responsibility of the global IPM facility (Maredia, 2003). Many countries established IPM centres for coordinating IPM activities but their strategies are different in various countries. For example, in the USA, United States Department of Agriculture (USDA) has a national IPM network. Similarly, India has a National Centre for IPM (NCIPM) in New Delhi (www.ncipm.org.in/).

Australia has been actively involved in biological control of pests and weeds since the early 1900s (Wilson, 1960) and various tactics compatible with IPM had been employed in north-eastern Australia (and elsewhere) (Williams and Il'ichev, 2003). Several centres were established in Australia during the 1990s for coordinating IPM activities. For example, The Centre for Tropical Pest Management (CTPM) (1994–1998) was a joint venture that involved departments of agriculture and universities working together on the national IPM program in Australia. With the demise of the CTPM in 1998 the University of Queensland established the Centre for Biological Information Technology (CBIT) to develop high quality, innovative software products to inform, educate and train students, practitioners and others involved in agricultural and natural resource management, particularly pest management (Maredia, 2003; Maredia et al., 2003). Currently departments of agriculture, universities, and crop industries are working on IPM programs. Some private organisations provide IPM services to the growers such as IPM Technologies Pty. Ltd. (www.ipmtechnologies.com.au). A few insectary companies provide a crop monitoring service to help growers with IPM (www.goodbugs.org.au).

Integrated pest management was established on classical biological control (introduction of biological control agents for permanent establishment and long term pest control) for imported pests as well as augmentative biological control when needed. Integrated pest management in the Queensland citrus industry began in 1973 and approximately 75% of growers had adopted this program by 1991-1992 (Smith and Papacek, 1993). Williams and Il'ichev, (2003) reported that integrated pest management in Australia is most advanced in the pome and stone fruits, cotton, wine grapes and citrus industries. The pome fruit industries played an important role in the establishment of national guidelines for integrated fruit production as well as facilitation of the implementation of IPM (Williams, 2000). Similarly, in the cotton industry, growers, consultants, researchers and extension officers of the Cotton Research and Development Corporation (CRDC) and the former Australian Cotton Cooperative Research Centre together developed IPM guidelines for cotton (Williams and Il'ichev, 2003).

2.1.1 Definitions of IPM

Definition of IPM is important for a particular situation mainly for its implementation (Bajwa and Kogan, 2003). A survey recorded 67 definitions between 1959 (definition of integrated control) and 2000 (Bajwa and Kogan, 2002). For a long time reconciling multiple definitions has been tried as the definitions evolved. Kogan (1998) proposed the following concept that:

> “Integrated pest management is a decision support system for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that take into account the interests of, and impacts on producers, society and the environment”.

According to this concept IPM is a multi-disciplinary approach to pest management (Maredia et al., 2003). Integrated pest management is a knowledge-intensive, farmer-based approach that encourages natural control of pest populations (Indonesian IPM

Secretariat, 1997). Integrated pest management (IPM) has been referred to as a crop protection/pest management system with implications for both methodological and disciplinary integration in a socioeconomic context of farming systems (Bajwa and Kogan, 2002). In other words, IPM is an interactive system with multiple levels of combination (Kogan, 1998) and has a sound ecological basis that links agriculture with the environment, biodiversity, human health and sustainability (Maredia, 2003). Integrated pest management serves as a practical model for ecological theory as well as development for other agricultural system components. Species/populations, communities and ecosystems are the three basic ecological scales which serve as the model for IPM integration (Kogan, 1998).

Fitt and Wilson (2012) described the 2002 definition of IPM by the FAO as:

> "The careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to level that are economically justified and reduce or minimise risks to human health and the environment".

Two different types of IPM, strategic IPM and tactical IPM can be described (Morse and Buhler, 1997; Cumming and Spiesman, 2006). According to Barfield and Swisher (1994) strategic IPM is founded on a general understanding of the entire agroecosystem and should thus integrate strongly with conservation efforts and tactical IPM is more limited, representing primarily a responsible use of pesticides. It is considered that both strategic and tactical approaches are important to applied IPM (Fitt and Wilson, 2012).

2.1.2 Types of control (strategies) used in IPM

Integrated pest management (IPM) utilises all suitable pest control techniques. Maredia (2003) stated that IPM combines and integrates different strategies such as, biological control, behavioural control, biopesticides, botanical pesticides, chemical pesticides, cultural control, host plant resistance, mechanical control and transgenic plants; and quarantine and regulations. In addition, IPM includes pest prevention techniques, pest monitoring methods, biological control, pest resistant plant varieties, pest attractants and repellents, biopesticides, and synthetic organic pesticides (Tette, 1997). It also uses weather data as well as cultural practices such as rotation, mulching, raised planting beds, narrow plant rows and inter-seeding. The University of California, State-Wide Integrated Pest Management Project, in 1997, described IPM as a combination of techniques such as biological control, habitat manipulation, modification of cultural practices and use of resistant varieties. A more recent description of IPM integrated three types of control options namely biological, cultural and chemical control (Horne and Page, 2008). They concluded that chemical control should be used as a supportive mechanism and never used as a primary tool.

The focus of IPM on non-pesticidal techniques such as cultural control, introduction of resistant plants and biological control began in the 1980s and proposed a switch to biologically intensive or biointensive IPM. This relied on host-plant resistance, cultural controls, biological controls and biorational pesticides that are easily integrated with biointensive IPM systems (Frisbie and Smith, 1991; Uhm, 2002). Recently, the interaction between biological control and other forms of pest management such as induced plant defences, novel non-toxic plant protection compounds and sterile insect technique have been reviewed. The ways in which biological control can be integrated with the aforementioned forms of non-pesticidal pest management have been explored (Gurr and Kvedaras, 2010).

2.2 Biological control

Biological control of arthropod pests has a long history. Gurr et al. (2000) described practices in a Pre-Scientific Era, and proposed a chronological framework; Pre-Scientific Era (before-1880), Classical Era (1880–1939), Chemical Era (1939–1962) and Integrated Era (1962–present) to describe the overall development of biological control. Once humans began to practice agriculture the use of natural enemies to control pests was recognised, dating back to ancient times. In ancient China, citrus growers would place colonies of predaceous ants *Oecophylla smaragdina* (Dru) (Hymenoptera: Formicidae) in citrus trees to control caterpillars and large boring beetles (Williamson, 1998; Hajek, 2004). In the early 1800s, American naturalists and entomologists used predators such as syrphid flies **(**Diptera: Syrphidae**)** and coccinellid beetles (Coleoptera: Coccinellidae) to control aphids in greenhouses and outdoor crops (Van Driesche and Bellows, 1996). Gurr et al. (2000) noted that the term "Biological Control" was coined by H. S. Smith in 1919 during the classical era (1880–1939). In relation to plant pathogens the term "Biological Control" was first introduced by C. F. von Tubeuf in 1914 and then applied to arthropod pest control by H. S. Smith in 1919 (Baker, 1987). Furthermore, the importation of the predatory Vedalia beetle *Rodolia cardinalis* (Mulsant) (Coleoptera: Coccinellidae) was used in the classical era to control cottony-cushion scale (*Icerya purchasi* Maskell) (Hemiptera: Monophlebidae) in Californian citrus (Doutt, 1964). The first commercial production of *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae) began in Britain and elsewhere for greenhouse control of whitefly during the classical era (van Lenteren, 1995; Gurr et al., 2000). According to Gurr et al. (2000) commercial production of *E. formosa* ceased due to the availability of effective pesticides.

The entomopathogenic bacterium *Bacillus thuringiensis* (Berliner) (Bt) was first commercialised and extensively produced in the USA, some European countries and the former USSR during the chemical era (1939–1962) (van Frankenhuyzen, 1993). Progress was made in some areas of biological control but the total number of classical biological control introductions dramatically declined during this era (Greathead and Greathead, 1992).

In general, biological control had little support until the start of the integrated era (1962–present) (Gurr et al., 2000). During the beginning of the integrated era, the definition of integrated pest control was published by the United Nations (FAO, 1967) and pesticide dependency began to reduce. The use of classical, augmentative and conservation approaches to biological control began to increase (Gurr et al., 2000). In more recent years, biological control has developed into a large and diverse field but the traditional strategies remain the fundamental tools. Biological control uses living biological control agents for the control of pests which is based on a basic knowledge of the interactions of living organisms and provides a sound ecological basis for pest management (Daane et al., 2007). The brief history of the development of biological control indicates that biological control is now beginning a new era after the dominance of chemical control (Wratten and Gurr, 2000).

2.2.1 Definition of biological control

Biological control has been defined many times and in many ways. The term “Biological Control” was first used by H. S. Smith in 1919 who believed that insect pests could be controlled by the use of natural enemies such as pathogens, parasitoids and predators (DeBach, 1974).

Later DeBach (1964) defined biological control as:

> “The action of parasites, predators or pathogens maintains another organism’s population density at a lower average than would occur in their absence”.

This definition (DeBach, 1964) measured biological control both as an applied and ecological point of view as well as specifying biological control agents used to regulate the pest population in density-dependent relationships (Garcia et al., 1988). In addition, this definition excludes ambiguous definitions or what other scientists might call biological control.

Biological control is also defined as the effect of fixed actions by man, or may result from the unassisted action of natural forces that may be employed either for control of crop or forest pests, or for re-establishment of natural systems affected by non-native pests (Van Driesche and Bellows, 1996). They defined biological control as:

> “A population level process in which one species population lowers the numbers of another species by mechanisms such as predation, parasitism, pathogenicity or competition”(Van Driesche and Bellows, 1996).

The widely accepted definition of biological control is:

> “The use of living organisms to suppress the population of a specific pest organism, making it less abundant or less damaging than it would otherwise be” (Eilenberg et al., 2001).

2.2.2 Biological control in Australia

Biological control has a long history in Australia. In the early 1900s the Department of Natural Resources and Environment in Victoria released a parasitoid wasp *Aphelinus mali* (Haldeman) (Hymenoptera: Aphelinidae) to control woolly aphid and this wasp is still active today (Williams and Il'ichev, 2003). The first biological control project began in

1912 on cactus (Julien et al., 2007). In 1932 the control of the exotic weed, prickly pear (*Opuntia* spp), by *Cactoblastis cactorum* (Berg) (Lepidoptera: Pyralidae) was a widely recognised success story in Australia (Gurr et al., 2000).

Approximately 150 species of biological control agents have been introduced into Australia with the aim of classical biological control of arthropod pests (Waterhouse and Sands, 2001). Some introductions were not completely successful. The control of green vegetable bug *Nezara viridula* (L.) (Hemiptera: Pentatomidae), which is a pest of many horticultural and field crops in Australia and was attempted by the introduction of the egg parasitoid *Trissolcus basalis* (Wollaston) (Hymenoptera: Scelionidae). In southeast Queensland *N. viridula* remains a significant pest despite sometimes-high parasitism rates by *T. basalis*. In NSW and Queensland, *N. viridula* remains a major pest of soybeans and other pulses (Knight and Gurr, 2007).

Conservation biological control is the action that preserves or protects natural enemies (Ehler, 1998). In fact two types of strategies are involved in this control, conservation of natural enemies and enhancement of natural enemies. Many researchers noted that the Australian cotton industry is now encouraging the conservation and rehabilitation of natural areas and native vegetation which act as providers of multiple ecosystems services such as providing the non-crop resources required by biological control agents (Perovic et al., 2010).

2.2.3 Types of approach in biological control

Different researchers divided biological control in different ways. Biological control has three major approaches namely, importation or introduction, augmentation, and conservation (Landis and Orr, 1996; Van Driesche and Bellows, 1996). Augmentative biological control is then subdivided into inoculative and inundative methods (Landis and Orr, 1996; Van Driesche and Bellows, 1996; van Lenteren, 2000b). Biological control strategies can be grouped into four major approaches namely classical biological control, inoculative biological control, inundative biological control and conservation biological control (Hajek, 2004; Eilenberg, 2006).

They can be defined as:

1. Classical Biological Control: The intentional introduction of an exotic, usually co-evolved, biological control agent for permanent establishment and long-term pest control (Eilenberg et al., 2001).

2. Inoculative Biological Control: The intentional release of a living organism as a biological control agent with the expectation that it will multiply and control the pest for an extended period, but not permanently (Eilenberg et al., 2001).

3. Inundative Biological Control: The use of a living organisms to control the pests when control is achieved exclusively by the released organisms themselves (Eilenberg et al., 2001).

4. Conservation Biological Control: Modification of the environment or existing practices to protect and enhance specific enemies or other organisms to reduce the effect of pests (Eilenberg et al., 2001).

Inoculative and inundative biological controls have different goals but both also have some common features. They both augment the population of biological control agents and it is difficult to know what the effect on targets are from released biological control agents or from their progeny (Eilenberg, 2006). Therefore, inoculative and inundative biological control are usually treated together as "Augmentative Biological Control" (Hajek, 2004).

2.3 Augmentative biological control

Augmentative biological control involves one to several releases of biological control agents to suppress a pest during the course of a season or a crop's production cycle (Luck and Forster, 2003). The first augmentative biological control began sometime between 1913 and 1917 with the use of *Cryptolaemus montrouzieri* Mulsant (Coleoptera: Coccinellidae) to control citrophilous mealybug, *Pseudococcus calceolariae* Fernald, (Hemiptera: Pseudococcidae), a pest of citrus in Southern California. After this success *Trichogramma* (Hymenoptera: Trichogrammatidae) species began to be used as augmentative biological control agents in the late 1920s, when S.E. Flanders developed a mass production system for these biological control agents (Luck and Forster, 2003). The potential of augmentative biological control has been well recognised for many years (DeBach, 1964; Ridgway and Vinson, 1977; King et al., 1985).

Augmentative releases of biological control agents can be divided into two types: inundative and seasonal inoculative methods, although they are sometimes hard to distinguish. The sugarcane borer, *Diatraea saccharalis* (F.) **(**Lepidoptera: Crambidae) is controlled by the inundative release of *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae) in several countries of Latin America. The release of *T. basalis* against *N. viridula* in Brazil and the control of pests in greenhouses involve the periodic release of several biological control agents in Colombia (van Lenteren and Bueno, 2003). It has not been so successful in Australia especially in field crops.

Augmentative biological control is applied both in greenhouse and in open field crops. In greenhouses, many pests can be effectively controlled by the use of biological control agents because closed greenhouse systems have controlled and relatively stable environments. In open field crops, the uses of augmentative biological control agents are limited because more habitat-diverse crops grown in open fields and the environmental conditions are not stable (Huang et al., 2011). Another reason was that under this stable greenhouse environment pests reproduce very quickly and growers needed to increase pesticide application frequency. As a result pests develop pesticide resistance quickly.

Augmentative biological control was compared with chemical control by van Lenteren (2000a). He concluded that there is no residue/phytotoxicity on the crop, no water contamination and no premature damage of fruit and flowers. The release of biological control agents is safer and easier than pesticide application, continuous harvesting is allowed and there is no waiting period after application.

2.3.1 Augmentative biological control in the global context

Augmentative biological control is applied around the world. In Europe the first augmentative releases of biological control agents began in 1734 through the augmentative release of lacewings (Neuroptera) to control aphids (Sternorrhyncha) in greenhouses (Luck and Forster, 2003). Historically, the first big success story was seen using *E. formosa* to control *T. vaporariorum* before 1930 in the UK (van Lenteren, 2006; van Lenteren et al., 2006). However, it is very hard to get data on current use of augmentative biological control (van Lenteren and Bueno, 2003). Biological control agents in the former USSR were released on 10 million hectares and in China on 1 million hectares (Ridgway et al., 1977). Western Europe used biological control agents on <30,000 hectares and North America on <15,000 hectares. Van Lenteren (2000a) estimated the areas under augmentative biological control agents as in Figure 2.1.

Worldwide, approximately 20 species of *Trichogramma* were regularly used in augmentative biological control of Lepidopteran pests in about 22 crops and trees; for example, vegetables, cereals, and cotton in Russia (3–10 million hectares), China (2 million hectares), South America (1.2 million hectares), Mexico (1.5 million hectares) and Southeast Asia (0.3 million hectares) (Li, 1994). However, intensive use of pesticides and economic reasons such as higher labour costs constrain the more recent use of *Trichogramma* in Japan, South East Asia, South America, USA, Canada and Europe (van Lenteren and Bueno, 2003). Other commercial BCAs such as *Cotesia* spp., egg parasitoids, and *Orgilus* sp. are currently used worldwide (Cohen, 2010). The sweet potato whitefly, *Bemisia tabaci* (Gennadius) biotype B, (= *Bemisia argentifolii* Bellows and Perring) (Hemiptera: Aleyrodidae) has been controlled by introducing a mix of *Encarsia Formosa* (Gahan) and *Eretmocerus eremicus* Rose and Zolnerowich, (Hymenoptera: Aphelinidae) in Northern Europe and Northern America or *Eretmocerus mundus* Mercet (Hymenoptera: Aphelinidae) in the Mediterranean region (van Lenteren, 2000a).

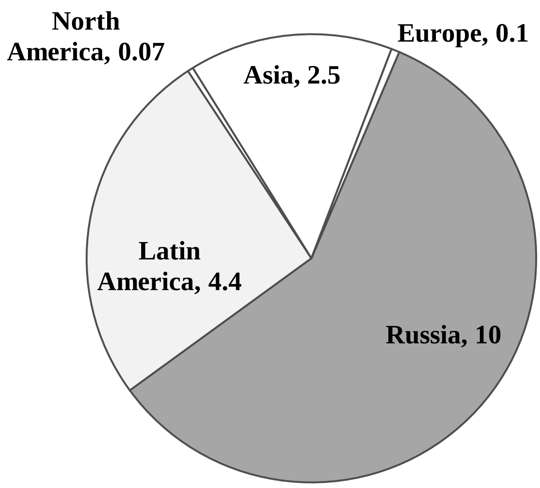

Figure 2.1: Estimated areas (in million hectares) under augmentative biological control in the world (van Lenteren, 2000a).

In Brazil and Latin America, the larval and pupal parasitoids are not used to a large extent in augmentative biological control in field crops, with the exception of the use of *Cotesia* parasitoids against sugarcane borers (van Lenteren and Bueno, 2003). In Denmark, augmentative biological control is the major pest control strategy being used in vegetable crops. The Danish government supports this practice with facilities for the implementation of biological control strategies (Eilenberg et al., 2000; Hajek, 2004). Similarly, in 1995, predatory mites, *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) were released on 50–70% of land producing cranberries to control two-spotted spider mite in California (Office of Technology Assessment, 1995). This predatory mite is use by many growers in greenhouses as well as in outdoor crops around the world (Pilkington et al., 2010; van Lenteren, 2012). In Spain 20,000 hectares of greenhouses now use augmentative biological control (commercial BCAs) which increases the total augmentative biological control treated greenhouse areas globally (Pilkington et al., 2010).

Augmentative biological control was used commercially in several crop types in Europe, for example, corn, apples, olives and in vineyards. In greenhouses, biological control agents were applied to strawberries, melon, watermelon, cucumber, tomato, sweet pepper and all vegetable crops and generated 80% of the global commercial revenue (van Lenteren, 2007; Pilkington et al., 2010). In addition, van Lenteren (2006) reported that augmentative biological control was used in various greenhouse cut flowers, other flowers and ornamentals in northern Europe and North America. More than 10% (600 hectares) of the total area with flowers and ornamentals in Dutch greenhouses were under augmentative biological control (commercial BCAs) in 1998 (van Lenteren, 2000b). This figure might be higher now as there is no official up to date report available. The most important commercial BCAs in Dutch greenhouses are *E. formosa, P. persimilis* and *Amblyseus cucumeris* (Oudemans) (Acarina: Phytoseiidae) (Blockmans, 1999).

In augmentative biological control entomopathogenic nematodes and invertebrate predators, parasites and parasitoids are more extensively used in greenhouses than in field crops (Hajek, 2004). The most frequent use of commercial BCAs is reported from The Netherlands, the United Kingdom, France and North American greenhouses. Commercial BCAs are used in more than 93% of the production of greenhouse tomatoes and peppers and more than 12% of greenhouse ornamentals in Canada (Murphy et al., 2002). The potential of augmentative biological control to suppress arthropod pests is well recognised but commercial use of these methods in outdoor crops is still relatively limited (Sigsgaard, 2005).

According to van Lenteren (2003b) an estimated 20% of commercial BCAs are used for field applications. Sigsgaard (2005) reported on current practices of commercial BCAs releases in outdoor crops in Europe. Examples are, *Trichogramma brassica* Bezdenko against *Ostrinia nubilalis* (Hubner) (Lepidoptera: Pyralidae) in maize (approximately 100,000 hectares), predatory mites against mites in vineyards (approximately 40,000 hectares) and predatory mites against spider and rust mites. In addition, commercial BCAs were also released against Lepidopteran and Hemipteran pests in orchards (approximately 30,000 hectares) and *P. persimilis* and other phytoseiid predatory mites are used to control spider mites in strawberries (less than 20,000 hectares) (Sigsgaard, 2005).

2.3.2 Augmentative biological control in Australia

In Australia, *Aphytis melinus* DeBach (Hymenoptera: Aphelinidae), a parasitoid wasp was the first commercially produced (1971) biological control agent. It controls the pest *Anonidiella aurantii* (Maskell) (Hemiptera: Diaspididae) (California red scale) in citrus crops (Furness et al., 1983). Later *Aphytis lingnanensis* Compere (Hymenoptera: Aphelinidae) was also used to control California red scale. The greenhouse whitefly, which is an important pest of tomatoes, cucumbers, tobacco and lettuce, is controlled effectively by the aphelinid parasitoid *E. formosa* (Caltagirone, 1981). Another example, a predatory mite, *P. persimilis*, has been used as a commercial BCA in Australia since 1984. It is widely and successfully used in both greenhouse and open field situations to control the two spotted spider mite in strawberries (van Lenteren, 2006). Trichogrammatid egg parasitoids are also used for augmentative biological control in Australia. The egg parasitoid *Trichogrammatoidea cryptophlebiae* Nagaraja (Hymenoptera: Trichogrammatidae) has been used successfully since the 2004–5 season to control macadamia nut borer, a major pest in macadamia production in Queensland (www.bioresources.com.au/MacTrix/index.html).

2.4 Commercial biological control agents (commercial BCAs)

According to different publications, globally the numbers of commercial BCAs have increased gradually and the number almost doubled between 2009 and 2011 (Table 2.1).

Table 2.1: Worldwide the numbers of species of commercial BCAs that are available.

Year of publication	Species commercially available
van Lenteren, 2003a	125
van Lenteren, 2007	150
Cock et al., 2010	170
van Lenteren, 2012	242

In different regions in the world, van Lenteren (2012) presented a full list of 242 commercial BCAs that are used (Figure 2.2). Studies reported that 115 biological control agents are commercially available in Europe and only 19 species available in North

America (USA and Canada) (van Lenteren and Tommasini, 2003). Warner and Getz (2008) reported that only 22 commercial insectaries produce a total of 38 macro-invertebrate species in North America. In the USA, commercial BCAs were used for pest management on only about 10% of greenhouses, 8% of nurseries, 19% of cultivated fruit and nut acreage, and 3% of the cultivated vegetable acreage (Office of Technology Assessment, 1995). It is clear that the commercial insectary industry and augmentative biological control are facing major challenges in North America in comparison with Europe (Warner and Getz, 2008). In Australia, only 23 species of insects, mites and entomopathogenic nematodes were available for augmentative biological control in 2002 (Llewellyn et al., 2002). This number increased to 31 commercial BCAs which were available by 2011 (van Lenteren, 2012). Currently 36 commercial BCAs are available in the Australian pest control market in 2014 (www.goodbugs.org.au).

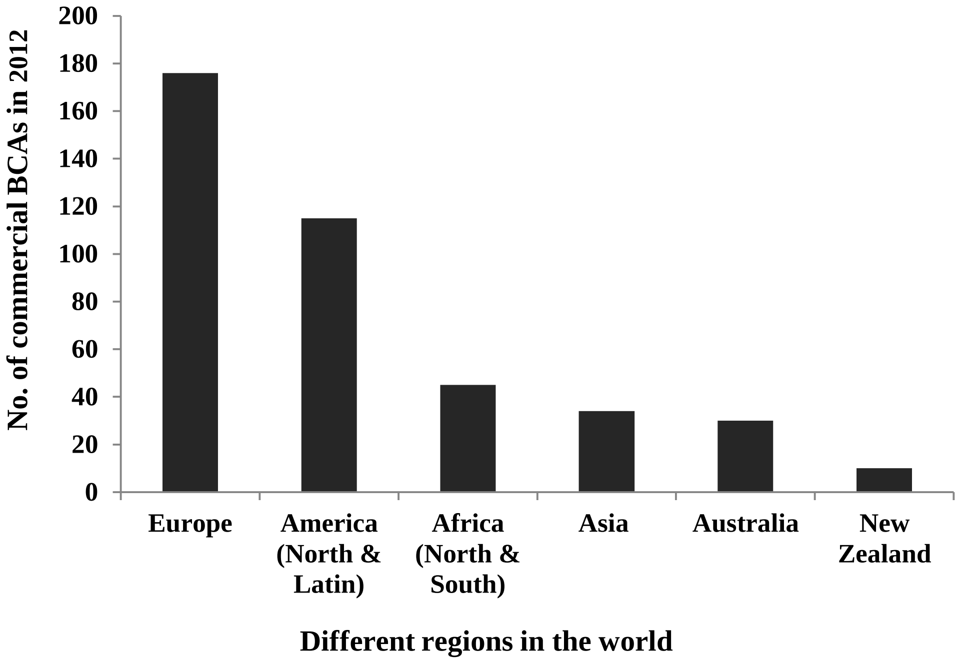

Figure 2.2: Commercial BCAs used in different regions in the world (van Lenteren, 2012).

Currently, commercial BCAs comprise microbial (fungi, viruses, protozoa and bacteria) and macrobial (entomopathogenic nematodes and invertebrate predators, and parasitoids) organisms. This study investigated only macrobial organisms. In recent years, interest has developed in using multiple commercial BCAs rather than a single agent in augmentative biological control of a particular cropping system. To address this researchers reviewed 167 projects and concluded that a single commercial BCA was sufficient to reduce pests in more than 50% of multiple-agent projects in which several species were released in a particular cropping system (Denoth et al., 2002). The introduction of multiple commercial BCAs in augmentative biological control adds to the complexity of a natural system as well as the negative effects on native flora and fauna.

The global crop protection market is approximately US$600 million in sales and commercial BCAs occupied only around 2% of this market (Anonymous, 2005). In Africa for example, in 2003 total annual commercial BCAs sales were valued at approximately US$23 million, including US$5 million for bacterial products (Guillon, 2004). In Kenya, total pesticide sales were valued at approximately US$57.4 million in 2002, of which only US$1.15 million (2%) were commercial BCA sales and mainly *B. thuringensis* (Bt)-based products (Wabule et al., 2004). Only 30 species constitute 90% of total global commercial BCA sales and 80% of this sale value comes from their use in greenhouses (van Lenteren, 2007).

2.4.1 Implementation of commercial BCAs

Commercial BCAs require positive publicity such as activities by government, local research centres and insectary industries. Most of the insectary companies are small enterprises and are not large enough to advertise their products alone. Most of the current insecticide companies spend a lot of money on advertising in order to convince farmers that chemicals are cheap, effective, easy and safe to use (Moser et al., 2008). Any type of biological control is a rapidly growing area which brings scientists together from different disciplinary backgrounds. Ecologists, entomologists, plant pathologists, weed scientists, insect pathologists and microbiologists are likely to be involved. Therefore, any type of effective biological control requires more research to combine and develop new and innovative approaches to achieve effective pest management (Hoy, 2009).

A previous study noted that successful implementation of commercial BCAs are highly dependent on crop-specific characters such as long-term or short term-crops, or vegetables or ornamentals (Van Driesche and Heinz, 2004). Innovation in commercial BCAs is not straightforward, and farmers need guidance when it is to be implemented (DeBuck and Beerling, 2006).

Most commercial BCAs are effective against only a small group of pest species and their efficacy is largely dependent on several factors such as physical, chemical, and biological environmental factors (Yano, 1993). Many researchers cited the growing number of commercial BCAs and commercial suppliers of biological control agents to indicate that the practice of augmentative biological control was expanding (Parrella et al., 1992; van Lenteren, 2003a). Others argued that augmentative biological control has not fulfilled its potential (Collier and Steenwyk, 2004). They claimed that augmentation achieved target densities in about 15% of case studies and failed 64% of the time as well as being less effective and more expensive than pesticides.

Van Lenteren (2006) reported that improved augmentation (rearing technology, releasing more species of natural enemies and integration with selective pesticides) had been implemented as long as 25 years ago. He also reported that on the present knowledge of natural enemies and modern agricultural production, biological control (including augmentative biological control) can be used to solve a considerable part of the current pest problems in agriculture and that conventional chemical control can be limited to 0–5% of its current use i.e. when using true Integrated Pest Management. For example more than 5000 modern and highly educated farmers in Northwest Europe reduced pesticide use of up to 100% in greenhouses while yields remained the same or even increased because phytotoxic effects of pesticides no longer occurred (van Lenteren, 2000a).

Successful augmentative biological control requires coordination of technical, scientific, agricultural, economic and social factors. The strengths and weaknesses of the commercial insectary industry strongly influence augmentative biological control. It is important to study the commercial insectary industry to determine the viability of augmentative biological control as a pest management strategy.

2.4.2 Different factors influence the adoption of commercial BCAs

There are numerous factors influencing the uptake of commercial BCAs by growers such as demographics, economic and growers' attitudes (Adesina and Zinnah, 1993; Sadati et al., 2010; Grogan and Goodhue, 2012). There is an extensive literature available on the adoption of agricultural technology. This literature as reviewed by several authors includes: a range of factors such as age, levels of education, access to labour, income, farm size, sources of information, environmental awareness and social networks that are positively related to the adoption of agricultural technology (Pannell et al., 2006;

Prokopy et al., 2008; Howley et al., 2012). A range of personal, social, cultural and economic factors as well as the characteristics of the innovation itself, influenced the adoption of agricultural technology (Pannell et al., 2006). Innovation is more likely to be adopted when it has a high ‘relative advantage’ (which depends on a range of economic, social and environmental factors) and its ‘trialability’ (easy to test and learn before adoption). Non-adoption or low adoption of a number of conservation practices is readily explicable in terms of their failure to provide a relative advantage or a range of difficulties that growers or landholders may have in trialing them (Pannell et al., 2006).

Several studies have shown a poor rate of IPM adoption worldwide (Wearing, 1988; Bajwa and Kogan, 2003). There are several reasons for the low adoption such as a lack of information, complexity, efficacy of chemical-based control and lack of entomologists and local advisors. In addition, most of the projects focus on research rather than implementation of IPM (Horne et al., 2008). There are some other barriers such as lack of pesticide regulations, poverty, contradictory societal messages to farmers, insufficient government funding and support, lack of training in IPM and lack of knowledge about agroecosystem complexity in the adoption of IPM (Cumming and Spiesman, 2006). In developing countries, the main obstacle for the adoption of IPM is insufficient training and technical support to the farmers (Parsa et al., 2014). Through trial and error IPM has proceeded to address all of these aforementioned issues.

Moser et al. (2008) reported that the adoption of commercial BCA is strongly affected by two factors namely the socio-economic environment in which they are to be applied, and farmers’ attitudes. The Californian citrus growers use the commercial BCA, *Aphytis melinus*, when they have more education and citrus acreage but marketing outlets, ethnicity and primary information sources had influence as well (Grogan and Goodhue, 2012). In terms of effectiveness, the quality of commercial BCAs is also an important factor. If growers have confidence with commercial BCAs then they are willing to experiment and adopt them. If, for any reason, a grower does not have confidence in them then they would be less prone to try them (Moser et al., 2008). In Australia, a survey of apple growers showed that the key factors that influence growers were the climate and topography of the orchard, the isolation of the orchard, the crop types in the region, the chemical and biological options and the cost and effectiveness of those options (Kaine and Bewsell, 2008). These factors have been poorly investigated in commercial BCA research and development programs. They need to be addressed for the implementation of commercial BCAs. This study investigated the citrus growers' attitudes (as a case study) towards the use of commercial BCAs in their pest management program.

2.5 Commercial insectary industry

The development of commercial insectaries began with citrus pest management in Southern California (Dietrick, 1981). Historically, the regional government organised many insectaries in Southern California (Luck and Forster, 2003). In the 1950s, the government-organised insectaries disappeared with the introduction of synthetic organic pesticides. Only the private and grower-owned insectaries remained (Graebner et al., 1984).

The commercial insectaries were first established in the USA where Everett J. Dietrick was the pioneer of the commercial insectary industry. In 1950, he started his first insectary in his garage in Riverside, California. Later in 1951, the Rincon-Vitova insectary was established by Stubby Green and Doug Green to produce *C. montrouzieri*.

These two insectaries (Rincon-Vitova and Dietrick's garage insectaries) were the first commercial insectaries in the world (Drlik, 1995). Today, Koppert is the world's largest insectary, which was started by a Dutch grower, J. Koppert (Van Driesche et al., 2008). DeBach (1964) reported that large-scale production of commercial BCAs began after the Second World War. In 1997, there were only 64 commercial insectaries worldwide, 26 in Western Europe, eight in Central Europe, ten in North America, five in Australia and New Zealand, five in Latin America, five in Asia and five in Russia (van Lenteren et al., 1997). Five years later there were about 85 commercial insectaries worldwide, 25 in Europe, 20 in North America, six in Australia and New Zealand, five in South Africa, about 15 in Asia (Japan, South Korea and India) and about 15 in Latin America (van Lenteren, 2003b). In 2009, there were 130 commercial insectary companies worldwide, of which 30 were larger (more than 10 people employed) and 100 smaller (2–10 people employed) companies (Cock et al., 2010). Van Lenteren (2012) reported that throughout the world, 530 commercial companies produced biological control agents in 2011, among them 30 larger companies (more than 10 people employed) and it was estimated about 500 smaller (2–10 people employed) companies. Both authors (Cock et al., 2010; van Lenteren, 2012) followed the same methods to review this information. Thus over the last 14 years (1997–2011) commercial insectary companies expanded rapidly around the world (Figure 2.3).

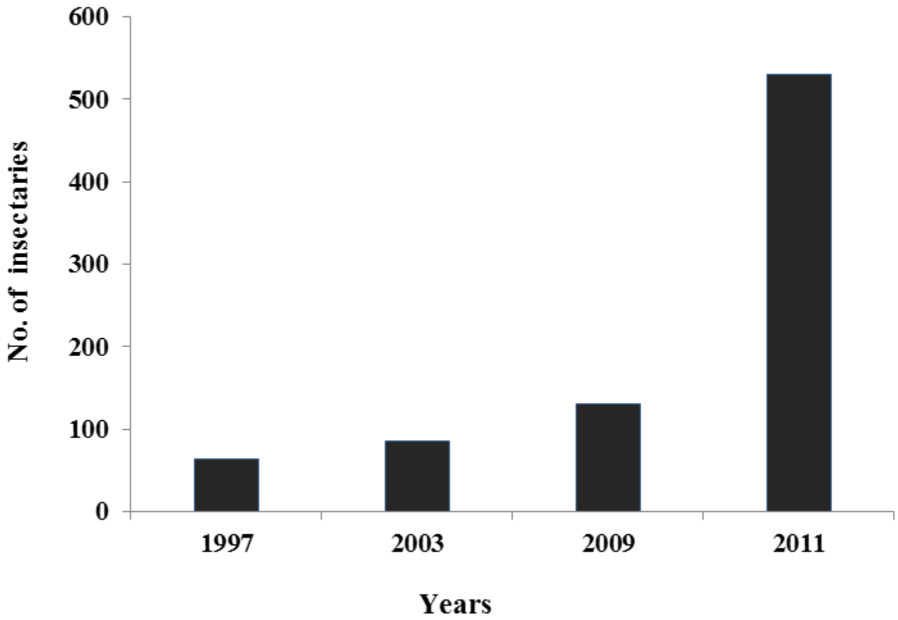

Figure 2.3: Worldwide increases in the number of commercial insectary companies (1997–2011) (including Australia) (The number of insectaries in different years sourced from the following articles: Cock et al., 2010; van Lenteren, 2012; van Lenteren et al., 1997; van Lenteren and Tommasini, 2003).

The commercial insectary companies mainly rear predators and parasitoids whereas only a few companies produce entomopathogenic nematodes. Microbial agents (fungi, viruses, protozoa and bacteria) are produced mainly by chemical companies. Commercial insectary companies are influenced by several factors including quality control which is the most important factor in their production, particularly if they rear the commercial BCAs on artificial diets. During mass-rearing this artificial selection may lead to reduced performance of commercial BCAs and use of these poor quality individuals leads to failure in pest management (van Lenteren, 2003b). Therefore, a quality control programme or assessment is necessary for commercially produced biological control agents (Sorati et al., 1996). Recently, the International Organisation for Biological Control/European Community (IOBC/EC) developed a full set of quality control guidelines for more than 30 species and these have been widely tested and adopted by commercial producers. In Europe, North America, Australia, New Zealand and Japan these guidelines are used for quality control of commercial BCAs. There are no publications in Australia and New Zealand on quality control of commercial BCAs, whereas in the former Soviet Union, China and Southern Africa there are some publications (van Lenteren, 2003b). These guidelines cover features that are relatively easy to determine in the laboratory such as emergence, sex ratio, life-span, fecundity, adult size and predation/parasitism rate (van Lenteren, 2003b).

Another major factor is government rules and regulations which govern commercial insectary industries. These regulations need to actively facilitate the use of commercial BCAs in order to support healthy agriculture and the environment, and should not slow down augmentative biological control (Glenister, 2004). Because of the current changes in regulatory practices for entry of beneficial insects, mites and nematodes into the USA, commercial insectaries and their customers can suffer the effects of these changes (Warner and Getz, 2008). Some commercial insectaries are largely dependent on long-distance transportation, as for example North American commercial insectaries who import some species from Europe and some insectaries which own or manage facilities in more than one country. Commercial insectaries face significant economic losses due to the change of rules for the importation of living organisms to the USA and face major challenges (Warner and Getz, 2008).

2.5.1 Insectaries in the global community

Many commercial and government funded insectaries produce biological control agents around the world. Ridgway and Vinson (1977) noted there were 50 North American suppliers of commercial BCAs, and later a survey reported 95 suppliers that produce 102 organisms for biological control (Hunter, 1997). In Africa, the demand for commercial

BCAs has increased in South Africa and Kenya. Dudutech (Kenya) Ltd and BCP Ltd were established in response to the demand from exporters (Cherry and Gwynn, 2007). However, there is limited uptake of commercial BCAs in local markets which have not reached sufficient capacity to establish local commercial BCA producers. There is a need to support community-level production and training for commercial BCAs. One successful example is in Cuba where government intervention to create local production of biological control agents acts to supply horticultural crops. Another example comes from India, where small farm and community based biological control agents' production continues to receive attention with the World Bank granting funds for establishing community based rural nucleopolyhedrovirus production facilities (CGIAR, 2005).

Many researchers claimed that the biologically based pest control market expanded rapidly (Ridgway and Inscoe, 1998). In 1995, the Office of Technology Assessment estimated that the global market for biologically (both micro- and macro-organisms) based pest control ranged from US$180–240 million and the commercial BCAs' market was US$40 million. That is commercial BCAs' (macro-organisms) sales are about 20% of the total market for biologically based pest control (Office of Technology Assessment, 1995). According to FAO 2009, the total market of the commercial BCAs was estimated at US$200–260 million (Tracy, 2014). This figure might be higher now as there is no official up-to-date report available. The USA biologically based pest control market ranges from US$95–147 million and commercial BCAs' market was US$8 million in 1995 which was about 6% of the total market for biologically based pest control in the USA (Office of Technology Assessment, 1995).

In 2003, the biologically based pest control global market reached US$588 million and commercial BCAs' value was US$190 million which was about 32% of the global biologically based pest control market (Guillon, 2004). But in North America, commercial BCAs constituted less than 10% of the biologically based pest control market and use of commercial BCAs appears to be static with declining demand in some species (Warner and Getz, 2008).

In Europe, the use of commercial BCAs in greenhouses began in 1968 and only two small commercial companies produced these agents. By 1997, greenhouse commercial BCAs' market value was more than US$30 million (Hajek, 2004). Pilkington et al. (2010) reported that the commercial BCAs' market in Spain is 30 million Euros (about US$41 million). There is no such data available in Australia. The current project will investigate the scale and viability of the Australian insectary industry.

2.5.2 Insectaries in Australia

In Australia, biological methods of insect control were first used commercially in 1944 by a few citrus growers at Merbein in the Sunraysia district. Biological Services Inc. was Australia's first commercial insectary, which was established by Ron George in 1971 at Loxton in South Australia (Furness et al., 1983). This company started with one biological control agent *A. melinus* (Furness et al., 1983). The Australian insectary industry produced only 23 species of insects, mites and entomopathogenic nematodes in 2002 (Llewellyn et al., 2002). These 23 biological control agents were six species of predatory mites, eight species of parasitoid wasps, one species of predatory ladybird, two species of predatory bugs, two species of predatory lacewings, three species of beetles and one species of entomopathogenic nematode (Llewellyn et al., 2002). After four decades since the first insectary establishment only seven commercial insectary companies produced 31 commercial BCAs in 2011 and in 2014, only five companies commercially operated in Australia because two of the small companies merged with two of the large companies (www.biologicalservices.com.au/history.html; www.goodbugs.org.au; Bugs for Bugs, 2015).

In 1994, the pricing and marketing by commercial BCAs' suppliers in the USA were reviewed and it was stated that knowledge of product prices is important for making calculations on the cost effectiveness of using commercial BCAs (Cranshaw et al., 1996). Van Lenteren et al. (1997) did a similar review of pricing and marketing for Europe. They reported that large differences exist between Europe and the USA in prices for commercial BCA. There is no such review or information about prices for commercial BCA available for Australian producers. There is no information available regarding the total annual sales of commercial BCAs in Australia.

Quality issues are another important factor for commercial insectaries and there is no Australian published guideline on quality control. However, in 1992, the Australasian Biological Control Association Inc. was established by the Australian and New Zealander commercial insectary owners. They also developed the Association's website with links to individual insectaries (Llewellyn et al., 2002). From this information, it is assumed that the Australian insectary industry is still in its infancy compared with the European and American insectary industries. Therefore, this project is being undertaken to conduct a comprehensive study of the commercial insectary industry to understand why it is not expanding to the same extent as in other countries and why augmentative biological control has an unfulfilled potential in agricultural production. The study focuses on the key stakeholders of this industry such as the Australian commercial insectary companies' owners, researchers who are conducting citrus pest management research in Australia and citrus growers.

Chapter 3: Research methodology

The chapter discusses the research design and theoretical framework employed in this research. It describes and justifies the social research methodologies which have been applied and the different social research tools that have been used to collect data. This is followed by the interview tool used for qualitative data collection. There is a discussion about the adoption determinants (demographics, economic factors, general information about citrus farm practices, grower perceptions, technology characteristics and institutional factors) in the questionnaire tool. A report summarising the results (Objectives 1, 2 and 3) was sent back to the participants (who had been previously interviewed) to get feedback from them.

3.1 Research design

The commercial insectary industry is situated within the broader plant protection system. This system is perceived as a complex adaptive social ecological system which includes many interacting components such as:

- farms and their human, natural, social and financial capital;
- the production landscapes in which the farms are situated;
- product value chains;
- input supply chains;
- plant protection expertise including available expertise in Integrated Pest Management (IPM);
- researchers and the research system; and
- government agencies and their associated actions, regulations and policies.

This study focused on the Australian commercial insectary industry which is a small component of this system. The study attempted to understand the phenomenon of the lack of growth in this industry in the context of this complex system. Figure 3.1 shows just the plant protection components of the system as linked through IPM, and locates the commercial insectary industry as just one of three approaches to biological pest control. In order to study the insectary industry in context, a number of components of this system were investigated through direct contact with the people involved. Data were collected on different perspectives and aspects of that complex system, and were synthesised with a focus on the possible interventions that could lead to an expanded role for the insectary industry and commercial biological control agents (commercial BCAs). The insectary industry commercially produces predators, parasitoid and nematode BCAs which are the agents for augmentative biological control of invertebrate pests, which is just one of the three biological control strategies. Biological control is one of many pest management strategies that can be employed when using an IPM (Figure 3.1).

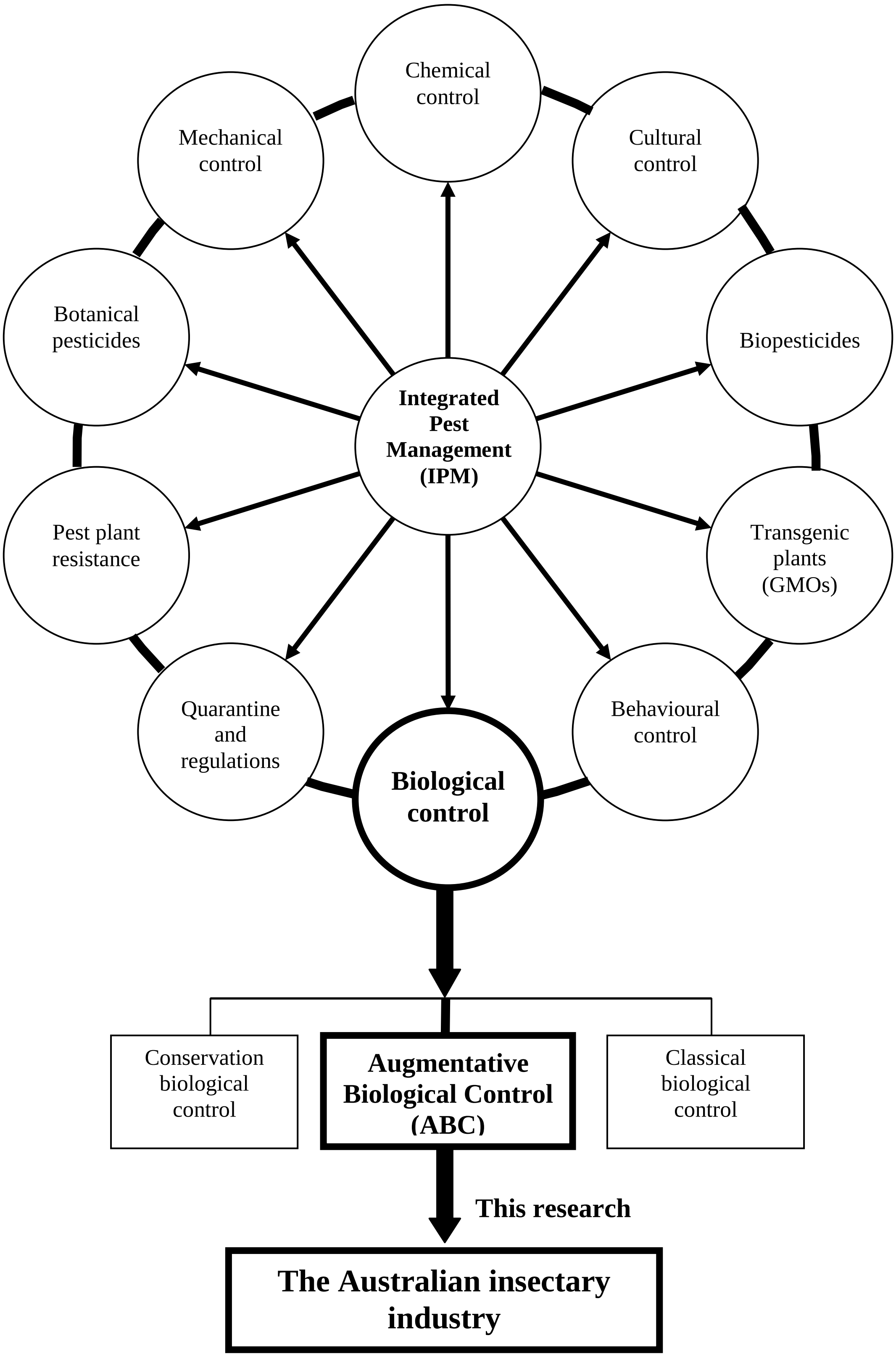

Figure 3.1: Different strategies under IPM modified from other studies (Bajwa and Kogan, 2002; Maredia et al., 2003) and this research.

The starting point for the research was the insectary industry itself. Desktop research and discussions with key informants clarified the broad characteristics of the industry. The small size of the industry made it feasible to interview all the Australian commercial insectary owners (a total of nine insectary owners) including two that are not currently engaged in commercial production. Out of these two insectary owners, one just closed his insectary very recently (end of 2010 and interviews were conducted in 2011) and for many years he operated this company. His experiences were very important for this research because the obstacles he had to face ended his company. The other one has a combination of experiences (a small scale insectary and IPM serveries to the growers) which was also very important for this research.

The citrus industry was identified as an appropriate focus to evaluate likely barriers to insectary industry expansion within a broader context. This is because commercial BCAs were first developed for citrus pests in Australia and these agents were commercially available in 1971. Some insectary owners specialise in citrus pest control agents, and citrus growers remain a key market for two insectaries. Citrus pest management researchers have been involved in the citrus industry for an average of about two decades. This involvement was either current or previous. It was therefore appropriate to interview samples of citrus pest management researchers (9) and citrus growers (9) to better understand scientific and practical components of the problem. Semi-structured interviews were conducted until the author judged that adequate and quality data have been collected to support the study (Walker, 2012). No new information or views were being expressed which indicated that data saturation had occurred. The interviews of the citrus growers provided the knowledge and understanding required to develop a questionnaire through which knowledge, experience and perceptions of growers could be quantified. The research process is summarised in Figure 3.2.

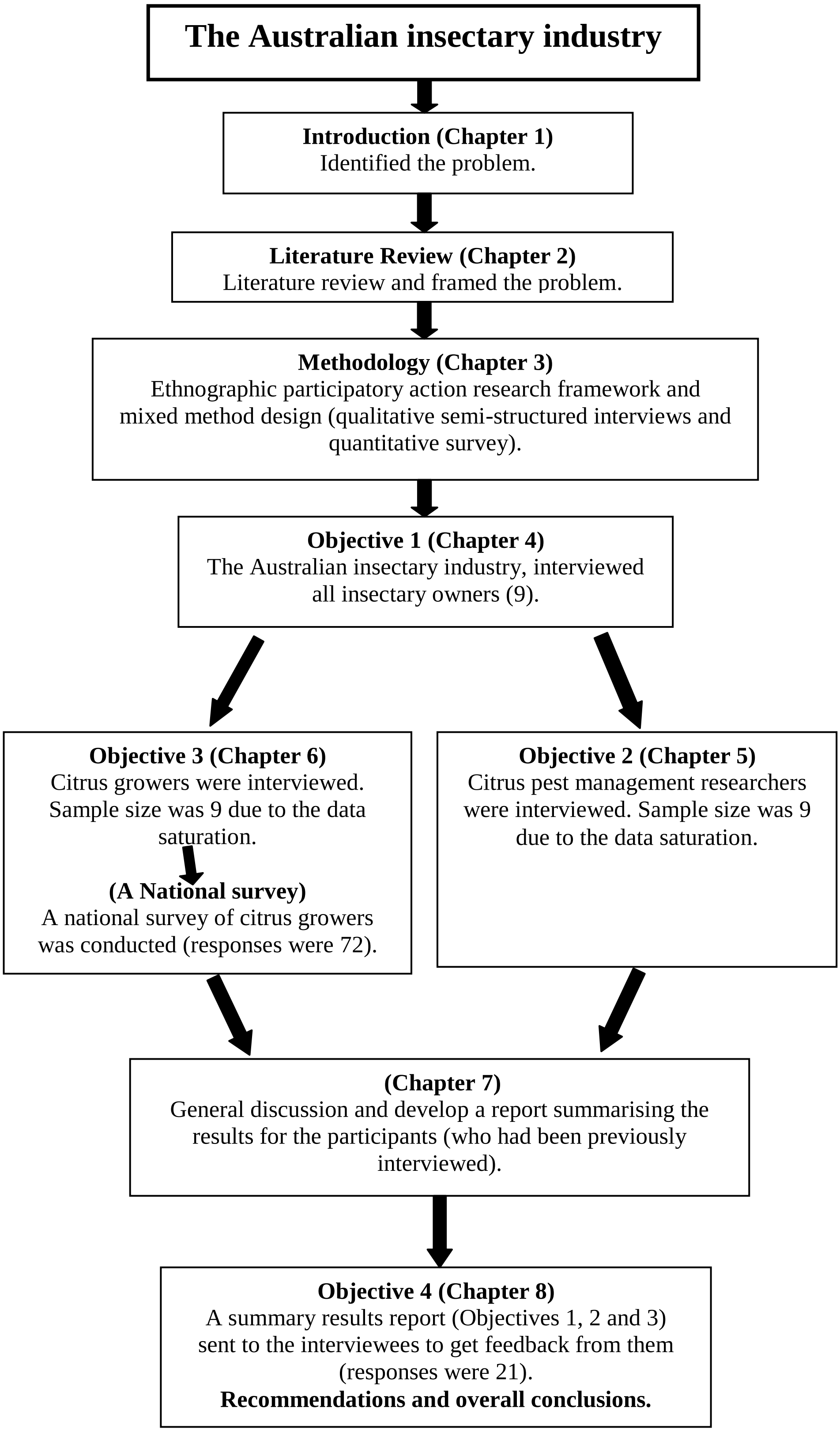

Figure 3.2: The research process.

3.2 Theoretical framework

There are three major theoretical approaches for qualitative research: Phenomenology, Ethnography, and Grounded Theory (Richards and Morse, 2007) (Table 3.1).

Table 3.1: Types of theoretical approach and the appropriate research questions.

Theoretical approaches	**Questions**
Phenomenology	Questions about the meaning or core or essence of phenomena or experiences. Focused on descriptions of what people experience, and how it is that they experience, and what they experience (Onwuegbuzie and Leech, 2005).
Ethnography	**Observational questions and descriptive questions about values, beliefs, and practices of cultural groups (what is going on here?) (Richards and Morse, 2007).**
Grounded theory	Process questions about changing experience over time or its stages and phases. Studies are usually situated in experiences in which change is expected, and the method has become dominant in research areas where the understanding of change, and process is central (Richards and Morse, 2007).

This research best fitted an Ethnographic approach, and is not appropriate for Phenomenological or Grounded Theory approaches. The ethnographic approach explores holistic insights or phenomena within the context of local customs, meanings and beliefs. It is used to study smaller subcultural units such as institutions, closed institutions (hospitals, nursing homes), or those with particular occupations such as doctors and nurses (Ager and Loughry, 2004; Richards and Morse, 2007). In this research, the insectary industry can be viewed as a smaller institution, while insectary owners, citrus pest management researchers and citrus growers are viewed as smaller subcultures. Therefore, this research adopted the ethnographic approach in addressing the overall research objectives about the expansion of the Australian insectary industry. This method is appropriate because the research is aimed at understanding in depth the Australian insectary industry, the researchers who are doing research on citrus pest management in Australia and citrus growers.

This project was planned based on a Participatory Action Research (PAR) framework. This is one of a number of specifically focused ethnographic approaches and was appropriate for this study because it focused on a particular industry (Georghiou, 1983; Richards and Morse, 2007). Normally this involves an intervention and evaluation of its impact then modification of the intervention in successive cycles where the researcher works in collaboration with the key stakeholders. In this project it was only possible to complete part of one action research cycle due to the time and budgetary constraints. Initially it was planned to organize a workshop in order to discuss the study and its recommendations and obtain industry feedback and initiate an ongoing action agenda. Due to time and funding constraints the workshop was cancelled. Instead a report was written to the stakeholders and got feedback from them to write Chapter 8 of this thesis and recommendations. If there was more time and funds for workshops then it would have been possible to discuss these recommendations with stakeholders about these recommendations, and develop further recommendations or guidelines for helping insectary owners to form a lobby group, or organize a petition to government or submitting application to the Horticulture Innovation Australia Ltd. for further actions that could facilitate and reduce the cost of adoption of commercial biological control agents by growers. Research was conducted with insectary owners, citrus pest management researchers and citrus growers and results were fed back to the participants through a summary results report to seek further input into the development of recommendations. Researchers (my supervisors and I) participated in the study to understand the total system and how it was operating, challenging stakeholders to explore the most appropriate steps towards the further development of the industry. The research team were agents for change within this industry and were active in the process of influencing its development. This approach is informed by and consistent with the PAR.

To obtain a deeper understanding of the Australian insectary industry qualitative methods are required. However, quantitative methods are required to determine the potential for industry growth. Therefore, the overall research design needed pragmatic mixed methods with an emphasis on choosing the most appropriate method for different objectives (Onwuegbuzie and Leech, 2005).

This can be defined as:

> "Integration of qualitative data with quantitative data to answer research objectives, or test hypotheses, addressing relationships between independent, and dependent variables" (Van De Vrie et al., 1972)".

The purpose of mixing qualitative and quantitative methods is to get information from multiple sources, and improve the quality of instruments used for data collection (Macqueen and Milstein, 1999; Ager and Loughry, 2004). This design can be used when one method alone does not provide a comprehensive answer to the research objectives (Richards and Morse, 2007).

Many researchers believe studies must take either a qualitative or a quantitative epistemological approach and that research paradigms and methodologies cannot be mixed (Rossman and Wilson, 1985). Other researchers have dismissed this polarisation because epistemology need not dictate the method of data collection or analysis (Onwuegbuzie and Leech, 2005; Cohen et al., 2007). When a research question demands a number of methodological approaches or choices include both qualitative and quantitative methods, mixing the two methods are beneficial (Tashakkori and Teddlie, 2003; Onwuegbuzie and Leech, 2005). It has been concluded that this research was best suited to a mixed method approach to provide in-depth understanding of the context then to quantify that understanding.

The following paragraph addresses the issue of researcher bias. The author has formal training in entomology and has strong interest in IPM, especially with regard to augmentative biological control and its implementation. Social research projects possess potential researcher bias in the stages of participant selection, survey design and qualitative data analysis. The following strategies were used to counteract this bias:

- key informants were consulted in formulating the research questions and research design;

- triangulation was achieved through the collection of qualitative data from three different groups of people involved in this industry: insectary owners, citrus pest management researchers and citrus growers;

- the entire population of insectary owners was interviewed;

- the samples of citrus pest management researchers and citrus growers were chosen according to objective criteria;

- interview transcripts were returned to respondents and adjustments were invited;

- The quantitative survey of citrus growers was formulated based on interviews from a sample of growers which continued until novel responses declined. This was taken as an indication that data saturation had been achieved;

- A summary report was prepared and circulated to the focus group and contributions were invited from the respondents.

3.3 Research tools used for the four specific Objectives

Objective 1 (Figure 3.2) required developing an in-depth understanding of the industry in context from the perspectives of the insectary owners. As the population size was only nine it was possible to interview the entire population including two whose insectaries are no longer in commercial production. As a result, semi-structured interviewing and qualitative analysis was the most appropriate tool for data collection and analysis. Chapter 4 addresses this Objective.

Objective 2 (Figure 3.2) addressed the perspectives of researchers (researching on citrus pest management) about the industry. Semi-structured interviews (9) were continued until it was judged that data saturation (no new information or views emerged) had been achieved. Data were analysed using qualitative analysis. It needed to uncover the underlying barriers that hindered the use of commercial BCAs in Australia from the researchers' perspectives. Chapter 5 addresses this Objective.

Objective 3 (Figure 3.2) Objective 3 (Figure 3.2) needed to understand the industry and its context from the perspective of citrus growers. It was also important to understand the extent to which views were representative of a larger population, approximately 2000 growers (Citrus Australia Ltd., 2011). To achieve this, both qualitative and quantitative tools were needed. Semi-structured interviews (9) were continued until data saturation had been achieved. Semi-structured interviews were used to better understand citrus growers' perspectives. These interviews helped to understand the citrus growers' attitudes towards the use of commercial BCAs which helped to develop a questionnaire for a national survey. The national survey was quantitative because there was a large population of growers. It was needed to generate quantifiable, reliable data from a sample that could be generalised to the larger population. Despite a concerted effort to recruit more respondents, only 72 participants completed the surveys. These small sample (72) data were compared to sparse national data to assess the similarity to the national citrus growers' population. In view of the low response rate in the survey, it is useful and appropriate to use the survey results to give qualitative inferences. Chapter 6 addresses this Objective.

Objective 4 (Figure 3.2) was addressed through the summary results report of Objectives 1, 2 and 3. It was necessary to send these results to the participants (who had been previously interviewed). A total of 21 responses were received. This Objective identifies the factors and their impacts on the Australian insectary industry. Their role in the concept of augmentative biological control in Australia is examined and develops recommendations for the Australian insectary industry, IPM practitioners, pest management consultants and policy makers. Chapter 8 addresses this Objective.

3.4 Methods

Before collection of data, ethics approval from the University of Sydney Human Research Ethics Committee (HREC) was required. Two applications (Stage I and Stage II) were submitted. The first application (Stage I) was for interviews with insectary owners and citrus growers and Approval Protocol no: 13278 (14th December 2010) was granted. The second application (Stage II) for surveys of citrus growers, interviews with researchers and feedback to the participants through a summary results report and Approval Protocol no: 14675 (19 April 2012) was granted.

As a part of the routine HREC process, prior to the interview each participant received a Participant Information Statement (PIS), consent form, and cover letter that outlined the researchers and organisations involved, and the purpose of the interviews (Appendix 1–3, cover letters). These documents also stated that participation was entirely voluntary for all aspects of the study. It explained that anonymity would be maintained through data aggregation, and by not naming participants directly. Only the research team would know their identity, and would not divulge it to a third party, and that survey participants were not privy to individual responses of other participants. Before conducting interviews a signed consent form was collected from each interviewee. In order to ensure maximum response rates all the interview participants were contacted initially by telephone or email to confirm their willingness to be involved in this interview. Each contact was brief, personalised and confidential. They were also informed that aggregated research results will be made available to them to assist with their business or policy objectives.

The Participant Information Statement for interviews included:

> "Being in this study is completely voluntary and you are not under any obligation to consent and if you do consent you can withdraw at any time without affecting your relationship with The University of Sydney. You may stop the interview at any time if you do not wish to continue the audio recording of the interview will be erased and the information provided and gathered will not be included in the study".

The Participant Information Statement for the questionnaire included:

> "Being in this study is completely voluntary and you are not under any obligation to consent to complete the questionnaire/survey. Submitting a completed questionnaire/ survey is an indication of your consent to participate in the study. You can withdraw any time prior to submitting your completed questionnaire/survey. Once you have submitted your questionnaire/survey anonymously, your response cannot be withdrawn".

Questionnaire survey participants received only questionnaires and Participant Information Statements (PIS) (Appendix 10, questionnaire). Consent was deemed to be given by survey completion.

In this study different data collection tools (instruments or techniques) were used for triangulation which provided different views of the research objectives. These tools were interviews, questionnaire survey, and a summary results report to the participants (who had been previously interviewed).

3.4.1 Interviews

Interviews reported in Chapter 4, 5 and 6

Interviews are most commonly used as data collection tools in qualitative research which supplement, and extend knowledge about an individual's thoughts, feelings, behaviour, and interpretations (DiCicco-Bloom and Crabtree, 2006; Woods, 2011). In the ethnographic research interview, it is the most important data-gathering tool that is used. The term 'qualitative interviews' is often used in qualitative research, and have been categorised into three types; unstructured, semi-structured and structured interviews (Bernard, 1988; DiCicco-Bloom and Crabtree, 2006) (Table 3.2).

In this ethnographic research study, a semi-structured interview was used (Table 3.2). This type of interview is neither an unstructured nor a structured interview nor a free conversation. Rather this type of interview regulates the order of questions and allows the respondents to tell a lot of detail. Respondents do not have to rely only on predefined concepts or questions of the interviewer. This kind of interview is more flexible than an unstructured or structured type. The semi-structured interviews aimed to understand the unique experiences of targeted samples (insectary owners, citrus pest management researchers and citrus growers). They also encouraged the respondents to freely discuss their ideas and opinions, and give more detailed answers to the questions. It is necessary to use open-ended questions as well as probing questions to obtain the detailed information required.

The pro-forma for each of the interviews in Chapters 4, 5 and 6 was developed based on the specific topics which addressed the research objectives. These are given in the Appendix 7–9 as described in Chapter 4, 5 and 6 (Figure 3.2). They are designed to elicit information about the insectary companies and commercial BCAs from the insectary owners (Chapter 4), citrus pest management researchers (Chapter 5) and citrus growers (Chapter 6). Most of the interview questions were based on the North American commercial insectary industry survey (Warner and Getz, 2008).

The limitations of the semi-structured interviews are the predefined topics and questions which addressed the research objectives. After an open-ended question an interviewer asks follow-up or probing questions. Through the follow-up question, the interviewer seeks more detail about the topic that was brought up by the respondents (Rogers and Shoemaker, 1971). Misunderstanding and misinterpretation of words are a limitation. To overcome these limitations interviews were recorded, transcribed, and then sent to the respondents for approval. Interviews were practiced with pilot "participants" prior to being conducted on the target population. This allowed the pro-formas to be adjusted, and provided practice for the interviewer.

Table 3.2: Types of interview appropriate for the data.

Interviews	Appropriate data
Unstructured interviews	Unstructured interactive interviews are appropriate when the researcher seeks to learn primarily from respondents what matters, or how procedure is understood, without interruption (Bryman and Bell, 2007; Richards and Morse, 2007). The researcher may not obtain data that is relevant to the question of the study, or respondents may talk about irrelevant, and inconsequential issues (Kajornboon, 2005).
Semi-structured interviews	**Semi-structured interviews are appropriate "when researchers are familiar enough with the study topic to develop an agenda, and questions about the topic in advance of interviewing (Bryman and Bell, 2007; Richards and Morse, 2007)". An initial open-ended question elicits responses that are on the top of the respondent's mind about the area of interest. The interviewer then follows up with questions, or probing questions seeking details on areas of interest to the researcher that have been brought up by the respondent. Participants not only respond to the questions that are asked by the interviewer, they are also involved in an extended dialog with the interviewer. They respond to the interviewer's questions and comments, and interact deeply with the interviewer (Macqueen and Milstein, 1999).**
Structured interviews	Structured interviews use a questionnaire format with pre-planned and closed questions which are frequently used to generate quantitative rather than qualitative data (Whiting, 2008; Woods, 2011). Respondents may not receive probing questions, or information to answer the question (Kajornboon, 2005; Woods, 2011).

In this study, semi-structured interviews were conducted with nine insectary owners (the total population) (Chapter 4) (Figure 3.2). Insectary owners were recruited through the Australasian Biological Control Association Inc. (www.goodbugs.org.au) webpage search and did not attempt to include other people (non-members of this association) who may be rearing biological control agents in Australia. A list of 14 citrus pest management researchers was compiled based on their publications and profile search through different institutions, namely the universities, state departments and the CSIRO (Chapter 5) (Figure 3.2). Subsequently nine researchers were interviewed due to data saturation (no new information or views emerged). The citrus growers were recruited through insectary owners, Citrus Australia Ltd. and pest management consultants (Chapter 6) (Figure 3.2). A list of ten citrus growers was compiled who were adults (over 18 years of age and growing citrus crop). Interviews were continued until the author felt that data had reached saturation (no new information or views were being expressed which indicated that data saturation had occurred) and stopped after nine interviews. Each interview was recorded (audiotaped) and initially estimated to take about 60–90 minutes. When studies used multiple methods (for example, in-depth interviews and survey) with the same population then those studies required fewer participants (Diane et al., 2002). Qualitative research is labour intensive and too large a sample collects repetitive superfluous data (Mason, 2010).

3.4.2 Questionnaire survey

Questionnaire survey reported in Chapter 6

Questionnaires are fundamental tools for acquiring information in social science research. A questionnaire can be defined as:

> “An instrument consisting of a series of questions or attitudes or opinion statements designed to elicit responses which can be converted into measures of the variables under investigation” (Franklin and Osborne, 1971)”.

In this study, one of the objectives (Objective 3, Figure 3.2) was to identify the factors behind the adoption of commercial BCAs by Australian citrus growers. To address this objective the self-administered questionnaire surveys were conducted throughout the Australian citrus growers because data can be collected from a large sample of the population within a short period of time. Other tools were not appropriate to address this objective.

An extensive literature exists that describes the many perspectives involved in the adoption of new technology such as commercial BCAs. The decision making process to adopt the technology is complex, continuous, and passes through different stages, such as awareness, interest, evaluation, acceptance and trial (Lionberger, 1960; Rogers, 1983). At each stage there are various constraints (such as social, economic, physical or logistical), and often a blend of income, profit, and institutional support is needed (Rogers and Shoemaker, 1971; Feder and Umali, 1993). It is important to understand the relationship between these factors and the process of new technology adoption (Tiwari et al., 2008).

The role of growers is critically important in the adoption of commercial BCAs and largely influenced by the growers' attitudes (Adesina and Zinnah, 1993; Sadati et al., 2010). It is strongly affected by two factors namely the socio-economic environment in which they are to be applied and farmers' attitudes. Several other factors such as social, economic, institutional, and environmental factors are also important (Chaves and Riley, 2001; Moser et al., 2008).

This study collected data to understand how to better promote the adoption of commercial BCAs. Data collection focused on six topics or categories (in the questionnaire each section represented each topic, Appendix 10) which are considered as potential determinants for adoption for pest management. These topics were:

i) Participants' information (Demographics),
ii) Economic factors,
iii) General information about citrus farm practices,
iv) Grower perceptions,
v) Technology (commercial BCAs) characteristics,
vi) Institutional factors.

i) Participants' information (Demographics)

Participants' information include: age, gender, education, location, farm ownership, farm managing experience, and number of employees. All these factors are considered as variables in the discussions below.

The age of a farmer influences the adoption process. In examples from the USA, in Georgia, the younger peanut farmer may be more knowledgeable about new technology and willing to take the risk to adopt IPM (McNamara et al., 1991; Sidibe, 2005). The older farmer in Texas has more knowledge, resources, and experience in profitable crop technologies and has less interest in adopting risky and complicated new technologies (Harper et al., 1990; Mauceri, 2004; Tiwari et al., 2008).

Gender has an impact on the new technology diffusion and adoption into rural settings. A previous study on the adoption of Precision Livestock Farming (PLF) technologies in Northern Australia showed that women graziers' play an important role in technology diffusion and adoption into rural settings. Women use most components of online technology three times more often than men (Hay and Pearce, 2014). Often women farmers do not have equal access to resources and this significantly limits their potential in enhancing productivity. For example the chances of new technology adoption are higher in male dominated societies such as Nepal (Tiwari et al., 2008).

Education is positively correlated to the technology adoption process and creates a favorable mental attitude for the acceptance of complex practices, or technologies (Waller et al., 1998; Ehler and Bottrell, 2000; Tiwari et al., 2008). Highly educated farmers have the ability to think analytically and adopt more agricultural technology than the less educated farmers.

Location is also important. Often technology developed in one agro-climatic condition may not be appropriate in another condition (Jensen et al., 1990). In this study, location is recorded according to the State or Territory, namely NSW, QLD, SA, TAS, VIC, WA, ACT and NT, and the number of respondent growers were counted in each state. Different States and Territories have different climatic conditions such as South Australia has a Mediterranean climate with cool wet winters and hot dry summers and Queensland has tropical and sub-tropical climates. As a result, different States and Territories have different insect pest problems or different biological control agents. The parasitoid (*Aphytis melinus)* of red scale is occurs widely in the inland regions of New South Wales, Victoria and South Australia. Another species, *Aphytis lingnanensis* occurs in Queensland (Furness et al., 1983; Papacek and Smith, 1992; Papacek, 2006; Dao, 2012).

Farm ownership is considered as a variable and often land ownership has positive influence on new technology adoption (Daberkow and McBride, 2003). Technology adoption is a decision making process and farm managing experience depends on owners, managers or both of them or others (Sidibe, 2005; Barungi et al., 2013).

The number of employees may positively or negatively influence technology adoption. For instance, in the United States, the greenhouse and nursery production survey showed that growers were more likely to use commercial BCAs when they have more full-time workers (Li et al., 2011).

ii) Economic factors

Economic factors include: farm size, crop values, pest management expenses, crop losses incurred and crop losses acceptable to the growers. All these factors are considered as variables in the discussions below.

Farm size is positively or negatively correlated with the adoption of new technology. For instance, in the California citrus growers' survey (2010), growers were more likely to use commercial BCAs when they have large citrus farms (Li et al., 2011; Grogan and Goodhue, 2012).

Often gross sales of crops are considered as a variable and have positive influence on new technology adoption. In the United States, for example, the Midwest greenhouse survey showed that commercial BCA users have higher gross sales of crops than non-users of commercial BCAs (Wawrzynski et al., 2001).

Pest management expenses especially higher pesticide costs, pushes farmers to find alternatives, and helps them to adopt a new technology such as IPM. The benefits and costs of different pest management strategies have an impact on pest management decisions (Williamson et al., 2003).

Reduced crop losses encouraged growers to adopt commercial BCAs into their crop management. The use of commercial BCAs in IPM programs in strawberry production has increased farmers' income and yields or remained the same (Moser et al., 2008). Crop losses are also an important factor because the adoption of commercial BCAs is related to the levels of losses that are acceptable to the growers.

iii) General information about citrus farm practices

General information about citrus farm practices include: crop varieties, market destination, intercropping, cover crops, IPM tools, economic threshold measurement, use of pesticides, use of commercial BCAs, monitoring biological control agents and decision maker. All these factors are considered as variables in the discussions below.

Crop variety was considered by growers. Some do not consider adopting capital-, or labor-intensive technology for low value crops for example when growers are supplying fruit for processing (Kaine and Bewsell, 2008). Conversely, a previous study reported that growers were willing to adopt IPM on high value crops or even in the same crop where yields are higher such as rice farmers in Texas (Herbert, 1995).

Market destination also influenced growers to adopt commercial BCAs. Different markets have different pricing and require different qualities especially in fresh products so the price difference can be very large (Urquhart, 1999). For instance, often fresh market fruit is not allowed the same level of damage, especially cosmetic damage, as fruit for processing (Kaine and Bewsell, 2008).

Intercropping is also considered as a variable in this study because intercropping systems have an ability to reduce the incidence of pests and diseases (Lithourgidis et al., 2011). Cover crops can enhance a wide range of beneficial insects that attack vineyard pests such as spider mite and leafhopper populations in grapes (English-Loeb et al., 2003; Irvin and Hoddle, 2015).

IPM tools, or a group of techniques such as cultural practices, conservation biological control, augmentative biological control, monitoring, chemical control and insect traps were used in this study to identify how many IPM tools farmers used for pest management. A previous study reported that economic thresholds and monitoring are essential components, or a prerequisite to practicing IPM (Lockeretz, 1991). The economic thresholds (developed as the population density at which control measures should be started to prevent an increasing pest population from reaching the economic injury levels) enhance growers' decision-making process (Bueno et al., 2011). Therefore, economic thresholds and monitoring biological control agents were considered as variables in this study. To monitor biological control agents, 5-point Likert-type scaled (Never-Always) questions were used.

Use of pesticides and commercial BCAs were considered as variables and were identified according to their type (broad spectrum or selective pesticides and different species of commercial BCAs), application frequencies, and targeted pests and diseases.

Decision making is a social process which can be influenced by the personality of the decision maker, their social networks, personal circumstances and family situation. (Pannell et al., 2006). The decision maker (who made decisions for pest management) had significant influence in the adoption of new technology. Often farmers made misleading decisions based on a prior belief, not on the true probabilities (Mazzocco et al., 1992).

iv) Grower perceptions

In the past some researchers found that grower perceptions have a significant influence on adoption decisions (Adesina and Zinnah, 1993; Hammond et al., 2006). Therefore, the 5-point Likert-type scaled questions were used to measure growers' views by asking whether they agree or disagree with several questions. Each Likert-type scaled question had several statements (items). These questions were: requirements for IPM practices, pesticide use, effects of insecticides on biological control agents, pesticide application strategies, why they do not use commercial BCAs, what influence takes place on decision making process, why they use commercial BCAs and non-user attitudes towards commercial BCAs.

v) Technology (commercial BCAs) characteristics

Technology characteristics are important in the adoption of new technology and often technology complexity has a significant influence on the speed of adoption (Batz et al., 1999; Pannell et al., 2006). In this study, technology characteristics were measured by using one 5-point Likert-type scaled question for the complexity of commercial BCAs in pest management. Another binary (YES/NO) question was asked about the time lag between chemical application and the application of commercial BCAs.

vi) Institutional factors

Institutional factors include sources of information and organisational help. All these factors are considered as variables in the discussions below.

Many studies concluded that reliable information is one of the important factors which were significantly associated with the adoption of IPM (Llewellyn, 2006; Samiee et al., 2009; Shojaei et al., 2013). The source of information is very important including workshops, field days, pamphlets and other farmers.

Organisational help such as extension services include promoting modern agricultural technologies. They are able to create a platform for acquisition of relevant information and change farmers' perception of risk associated with a technology's performance (Akudugu et al., 2012; Bonabana-Wabbi and Taylor, 2012). In this study, organisational help was measured by using 5-point Likert-type scaled question.

In this study the questionnaire was sent to all citrus growers after preliminary consideration of responses from nine growers. The six topics of determinants were considered by responses from the questionnaire returned (Chapter 6).

One fundamental limitation was that this survey does not permit an analysis of the dynamics or changing aspects of commercial BCA adoption. It collected cross-section data on commercial BCA user and non-user citrus growers. This survey does not show the characteristics of the same growers before and after they adopted commercial BCAs. Due to time constraints, it was not possible to follow the same grower over a period of time.

3.4.3 A results report (Objectives 1, 2 and 3) that was used for stakeholder feedback

Participants' feedback reported in Chapter 8

In Objective 4 (Figure 3.2) a report summarising the results from Objectives 1, 2, and 3 were sent to the interviewees who had been previously interviewed to get feedback from them. A summary of the results and the feedback from the participants helped to understand how interrelated variables affect one another and together developed the joint construction of the critical components of the commercial BCA adoption system. Then based on these final results, recommendations and overall conclusions were developed from this research.

Chapter 4: Insectary owners' interviews

Integrated pest management (IPM) involves multiple coordinated strategies or tools to control pests and augmentative biological control is one of them. It was important to first focus on the insectary owners who produce commercial BCAs and their stakeholders to better understand the commercial insectary industry and its lack of growth.

This Chapter addresses the specific Objective 1 (Chapters 1 and 3, Figure 3.2):

> To identify the factors which may hinder the Australian insectary industry's growth or be necessary for its expansion from the perspectives of the insectary owners?

To address this Objective 1 the author interviewed all of the Australian commercial insectary owners that were members of the Australasian Biological Control Association Inc. (www.goodbugs.org.au) because insectary owners are the key informants of this industry. The chapter identified the insectary owners' perspective which uncovered the fundamental barriers in production, marketing and distribution of commercial BCAs in Australia. This chapter also identified the major drivers that influence the Australian pest control market.

4.1 Introduction

The adoption of commercial BCAs are largely dependent on the insectary industry because this industry is the major source of commercial BCAs (O'Neil and Obrycki, 2009). The success and failure of this industry was also dependent on different factors which influenced the activities of the individuals and institutions engaged in commercial BCA production and release (Warner and Getz, 2008). To understand these factors, it is essential to study the commercial insectary industry. This helps to assess the potential and long-term sustainability of augmentative biological control as a pest management strategy in IPM (Warner and Getz, 2008; Cock et al., 2010).

In Australia, the first commercial insectary (Biological Services Inc.) was established in 1971 at Loxton, South Australia. This insectary was operated by R.S. George and he was the pioneer of the Australian commercial insectary industry (Furness et al., 1983). This industry is not expanding at the same rate as those in Europe and the USA. After four decades only seven insectary companies produced commercial BCAs in 2011 for the Australian market (www.goodbugs.org.au).

4.2 Methods

During 2011, nine commercial insectary owners (9) were interviewed, including seven that were operating commercial insectaries in 2011 and two whose insectaries are no longer in commercial production in Australia. Interviews were conducted by the author. Ethics approval was granted by the University of Sydney Human Research Ethics Committee before the interviews commenced (Approval protocol No: 13278, 14th December 2010). Participation was entirely voluntary and all owners agreed to be interviewed. They were identified from the membership list of the Australasian Biological Control Association Inc. (www.goodbugs.org.au). The author did not attempt to include other people who are not members of this association who may be rearing biological control agents.

Each insectary owner was invited to participate by telephone or email. Motivation to participate was stimulated by emphasising the relevance of the study to the future directions of each individual business and the industry as a whole. Each contact was brief and personalised and they were informed that aggregated research results will be made available to them to assist with their business or policy objectives. Before conducting the interviews each respondent received a Participant Information Statement (PIS), consent form and cover letter (Appendix 1). Maintaining anonymity was difficult due to the small size of the industry but was achieved through de-identification and data aggregation.

Nine semi-structured interviews were conducted, seven in person (face-to-face) and two by telephone because the insectaries were located a long distance away from Sydney. In these interviews, the interviewer guided a conversation based on a flexibly applied interview protocol. Initial questions were broad and open-ended to elicit key issues that were important to respondents, with follow-up or probing questions seeking detail on the issues raised and those of importance to the study. An interview pro-forma (Appendix 7) was developed based on areas which included the history of the owners' involvement in the industry and their opinions about the social, political, biological and technical barriers facing the industry. Quantitative data were collected on the economic situation of the companies such as set up costs, products, customers and sales. Pilot interviews were conducted to refine the protocol prior to conducting formal interviews on the population of nine insectary owners.

The interviews were recorded (audiotaped), with an average length of 99 minutes, and then interview responses were transcribed using Express Scribe software (Express Scribe v 5.55© NCH). Before analysis, the transcribed text of the appropriate interview was sent to each insectary owner for approval. If necessary a follow-up telephone call or email was made. The Good Bug Book (Llewellyn et al., 2002) or website (www.goodbugs.org.au) was checked to clarify the interview responses and to gather further information such as products name, target pests and crops.

Analysis of insectary owners' interviews

During the process of conducting and transcribing the interviews, themes emerged from the data that informed the analysis. These themes were further developed and added to during and after the process of coding the transcriptions. Transcribed text data were coded using NVivo 10.0 text analysis software. In this process, structural coding was used (Namey et al., 2008). The interview pro-forma (Appendix 7) was topic-based with questions grouped into different topics of inquiry namely:

1. General information,
2. Products and services,
3. Customers,
4. Company at present,
5. Company in future,
6. The Australian insectary industry.

According to the structural coding each topic was coded as: GINFO for General information, PRO-SER for Products and services, CUS for Customers, C-PRESENT for Company at present, C-FUTURE for Company in future and A-IINDUSTRY for The Australian insectary industry. Within a topic each question was given a code name which contained a prefix for the topic and an identifier for the question such as: GINFO_involvement, PRO-SER_major pro and ser, CUS_customers' list, C-PRESENT_set-up cost, C-FUTURE_optimistic and A-IINDUSTRY_expansion. The full list of these codes appears in Table 4.1 under the headings: General information, Products and services, Customers, Company at present, Company in future and the Australian insectary industry.

Table 4.1: Interview code (node in NVivo) descriptions. Six topic codes and each topic code has a group of question codes.

Code	Code descriptions
1. Code: GINFO	**General information**
GINFO_involvement	Insectary owners' involvement in this industry.
GINFO_present condition	How insectary owners get to the present condition.
GINFO_difficulties	Difficulties faced to establish this company.
GINFO_overcome	How they overcame difficulties when they established an insectary company.
GINFO_location	Is location important for set-up of an insectary?
GINFO_decision	How they made the decision to establish an insectary?
GINFO_background	Insectary owners' background.
GINFO_hope	What they hope to achieve from the insectary business.
GINFO_goals	Specific goals or objectives from the insectary.
2. Code: PRO-SER	**Products and services**
PRO-SER_major pro and ser	Major products and services.
PRO-SER_product list changed	Product list has changed over the years.
PRO-SER_start new one	Bring a new species to the market.
PRO-SER_product get	Insectary owners retail other products or not.
PRO-SER_rearing	Commercial BCAs reared onsite or not?
PRO-SER_best seller	Best selling products.
PRO-SER_sales activities	Sales activity by product volume.
PRO-SER_services	Other services provided to the customers.
3. Code: CUS	**Customers**
CUS_customers' list	Customers' list by total, percentage or industry segments.
CUS_important customers' needs	Important customers and their needs.
CUS_agri and others	Products sold to agriculture and other areas.
CUS_product shipment	Products sent to customers outside Australia or not.
CUS_bca use pest	Customers use commercial BCAs for which pest.
CUS_cus list increasing or decreasing	Customers' list increasing or decreasing over the last ten years.
CUS_switch ipm	Factors that influence customers to switch from conventional control methods to IPM.
CUS_evaluate	How they evaluate these factors.
CUS_land use	Record keeping about the land areas treated with commercial BCAs.
CUS_marketing strategies	Marketing strategies to promote product sales.
4. Code: C-PRESENT	**Company at present**
C-PRESENT_set-up cost	Company establishment costs (up-front cost).
C-PRESENT_employees	Full-time and part-time employees.
C-PRESENT_gross sales	Estimated gross sales.
C-PRESENT_costs and sales compare	Compared costs and sales.
C-PRESENT_factors	Factors favouring commercial BCAs or increased commercial BCAs sales.
C-PRESENT_GM crops	Impact of GM crops on business.
C-PRESENT_barriers	Main barriers for this industry.
C-PRESENT_quality	Product quality and customers' perception about quality.
C-PRESENT_guidelines	Do insectary owners follow national and international guidelines?

Code	Code descriptions
C-PRESENT_research	Do insectary owners work with researchers to maintain product quality?
C-PRESENT_memberships	Memberships with different associations.
5. Code: C-FUTURE	**Company in future**
C-FUTURE_optimistic	Insectary owners' optimism about their company.
C-FUTURE_future research	Insectary owners' future research for a new commercial BCA.
C-FUTURE_critical decisions	Insectary owners' future critical decisions.
6. Code:A-IINDUSTRY	**The Australian insectary industry**
A-IINDUSTRY_expansion	Factors that affect expansion of the Australian insectary industry.
A-IINDUSTRY_opportunities	Opportunities exist for public policies that favour commercial BCAs as alternatives to pesticides.
A-IINDUSTRY_current rules	Impact of current rules on the expansion of this industry.
A-IINDUSTRY_tandem use pesticides	Opinion about the tandem use of selective pesticides in IPM.

This coding was used to generate NVivo queries which were used to interrogate the data and formed the basis for further analysis and interpretation. The coded data were then categorised or classified according to emerging themes where the meaning of responses was consistent and unambiguous. Through this process, all examples of each theme were pulled together so that the results could be interpreted for that theme.

All quantitative data were analysed using total values because the total population was only nine and the whole population was interviewed. Some questions were not relevant to all the insectary owners because one insectary had closed down recently (in 2010) after ten years of operation and another does not produce insects on a commercial scale.

4.3 Results

The results of the analysis of the interview responses are given below under the five key themes and these themes became the sub-headings for the results (Table 4.2). The results were updated where relevant.

Table 4.2: Five themes identified from analysis of interviews with insectary owners.

Themes	Name of the Theme
4.3.1	History of the Australian commercial insectary industry.
4.3.2	Current status of the Australian insectary industry.
	4.3.2.1. Products and services.
	4.3.2.2. Industry size.
	4.3.2.3. Who purchases commercial BCAs in Australia?
	4.3.2.4. Quality control of commercial BCAs in Australia.
	4.3.2.5 Marketing of commercial BCAs in Australia.
4.3.3	Main barriers in Australian insectary industry.
4.3.4	Main driving factors in Australian commercial BCAs' market.
4.3.5	Opinion and recommendations by the Australian insectary owners.

4.3.1 History of the Australian commercial insectary industry

Interviews with insectary owners confirmed that the first commercial insectary company was established in 1971 at Loxton, South Australia. Initially, this company produced only the parasitoid wasp *Aphytis melinus* DeBach (Hymenoptera: Aphelinidae) to control red scales *Aonidiella aurantii* (Maskell) (Hemiptera: Diaspididae) in citrus crops. The second commercial insectary company was established in 1981 in Queensland and initially produced another species of parasitoid wasp, *Aphytis lingnanensis* Compere (Hymenoptera: Aphelinidae) to control red scales in citrus crops. The two different *Aphytis* species that are successful in South Australia and Queensland relates to the different climatic conditions in these two parts of Australia. These two companies are still operating and produce several other commercial BCAs and other IPM products. There have been no further companies established based on *Aphytis* spp. since 1981.

The development of pesticide resistance in two-spotted spider mites *Tetranychus urticae* Koch (Acari: Tetranychidae) emerged during the early 1970s (Unwin, 1973; Edge and

James, 1982, 1986; Herron et al., 2001). This provided an opportunity for the expansion of the industry. In 1981 a company was established in Victoria which produced *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae), a predatory mite for the control of two-spotted spider mites, *T. urticae* in different crops. That company closed in 1997 but six new companies were established during the period 1991–2001 in three different states, five which produced commercial BCAs and the remaining one did not. Three of the five new companies initially produced *P. persimilis* to control two-spotted spider mites. The climatic conditions in the states other than Victoria were more favourable in producing the *P. persimilis* commercial BCA. Among the remaining two one produced nematode biological control agents and another produced parasitoid wasps. This expansion of the insectary industry was primarily based on one commercial BCA, *P. persimilis*, which was the only available agent effective against the two-spotted spider mite during that time. Another new company producing *P. persimilis* was established in 2002 bringing the total to eight excluding one that did not produce commercially, but this became seven in 2010 when a company, also producing *P. persimilis*, was closed (Figure 4.1). No new insectaries have been established since 2002. In 2011 seven insectaries produced commercial BCAs commercially. By 2014, only five companies mass reared commercial BCAs in Australia because in that year, two of the small companies merged with the two bigger companies (www.biologicalservices.com.au/history.html; Bugs for Bugs, 2015). This result showed that the Australian commercial insectary industry was started with the production of *Aphytis* spp. for citrus pests. Then it was expanded based on *P. persimilis* to control two-spotted spider mite reaching eight insectaries (excluding one that did not mass-rear) in 2002. After this expansion, the industry became static. One insectary closed and two others combined with larger ones to give a total of five in 2014 (www.biologicalservices.com.au/history.html; Bugs for Bugs, 2015).

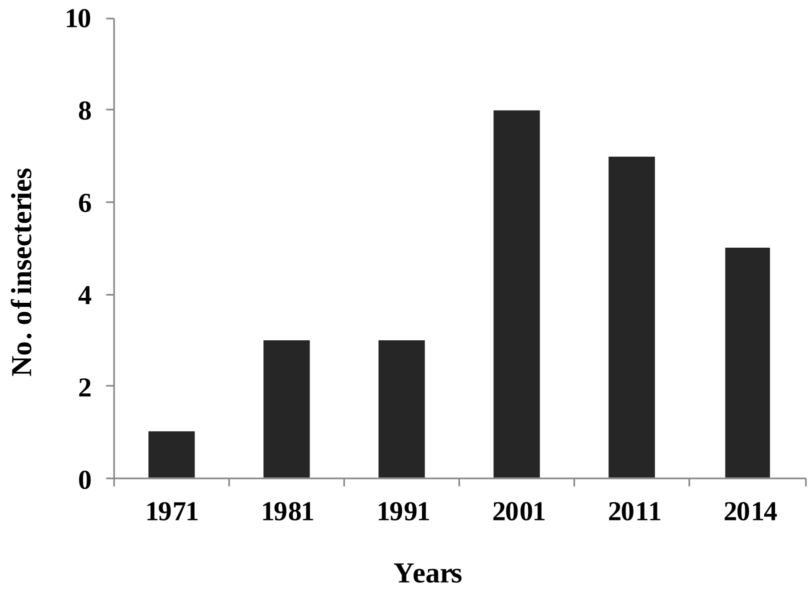

Figure 4.1: Australian commercial insectary companies from 1971–2011 and 2014. Updated from the Bugs for Bugs and the Biological Services websites (www.biologicalservices.com.au/history.html; Bugs for Bugs, 2015).

It was clear from the interviews that the establishment of a new company is very challenging. One insectary owner stated:

> "…we had many things to learn about how to breed insects that we didn't know enough about at the start. We needed to also get equipment together and make all of our own equipment, also train people and understand ourselves how best to optimise the production systems."

Seven insectary owners became involved in this industry through employment with an established insectary or other organisations, with two finding the work completely fascinating. Thus operating an insectary is a very specialised business which requires a high level of personal commitment and extensive training and experience.

4.3.2 Current status of the Australian insectary industry

This section presents results mainly on the basis of 2011 interviews that were conducted with the Australian insectary company owners. This section describes results of seven insectary owners who were all male and mass rearing commercial BCAs. These results were updated where relevant. To determine the current status of the Australian insectary industry this study identified five sub-themes (Table 4.2). These are discussed below:

4.3.2.1 Products and services

Seven Australian insectary companies produced commercial BCAs for pest control in 2011. Two insectaries (insectaries 1 and 2) primarily produced commercial BCAs for citrus pest (red scale pests) (Table 4.3). These two insectaries also produced multiple (more than ten species) commercial BCAs for different crops and have several major products. More than half of the insectaries (insectaries 3, 5, 6 and 7) produced one to three commercial BCAs and three of them (insectaries 3, 5 and 6) have produced only one product for the last 10–20 years. Three of them (insectaries 3, 5 and 7) produced the same species of commercial BCA (*P. persimilis*) for two-spotted spider mite pest and mainly focused on the same crops. The remaining one (insectary 4) focused on nematode commercial BCAs and produced six species of nematodes (Table 4.3). This result shows that market competition exists in the Australian commercial BCAs market because the same species is produced by several companies and they serve the same customers. This industry is entirely domestic and the market is not big enough.

The Australian commercial insectary companies produce 31 species of commercial BCAs in 2011 (Table 4.4). All produce arthropod commercial BCAs except one which produces only nematode commercial BCAs. Only two companies produced most of the commercial BCAs. The most widely used commercial BCA in the Australian market is *Neoseilus cucumeris* (Oudemans) (Acarina: Phytoseiidae) (total production, 1333 million mites per year) in 2011. The second and third products sold are *Aphytis* (total production, 554 million wasps per year) and *P. persimilis* (total production, 133 million mites per year).

During the period 1975–2010, several other commercial BCAs were introduced and then discontinued from the Australian market. For example, *Orgilus lepidus* Muesebeck, (Hymenoptera: Braconidae) (Potato tuber moth parasitoid) was introduced in 1998 but after two years it was discontinued. Discontinued agents were not included in this analysis because the insectary owners were not able to give detailed data about them.

Table 4.3: The Australian insectaries producing commercial BCAs in 2011 and their use in Australia. The Good Bug Book (Llewellyn et al., 2002) and (www.goodbugs.org.au) website were also consulted for this result.

Insectary companies	Commercial BCAs produced	Target pests	Target crops
Insectary 1	Multiple species of wasps, mites and beetle: *Aphelinus abdominalis*	Greenhouse aphids, (green peach, potato, and foxglove).	Flowers/ornamentals, greenhouse capsicums and eggplants.
	Aphidius colemani	Aphids (green peach and melons).	Flowers/ornamentals, greenhouse cucumbers and melons.
	Aphytis melinus	Red scale.	Citrus.
	Dalotia (Atheta) coriaria	Fungus gnat, onion thrips, Western flower thrips.	Flowers/ornamentals, greenhouse cucumbers, eggplants, capsicums and tomatoes.
	Encarsia formosa	Silverleaf whitefly, greenhouse whitefly.	Flowers/ornamentals, greenhouse cucumbers, and capsicums.
	Eretmocerus warrae	Greenhouse whitefly.	Berry fruit, flowers/ ornamentals, greenhouse cucumbers, capsicums, eggplants, tomatoes and strawberries.
	Hypoaspis aculeifer	Bulb mite, chicken mite, onion thrips, Western flower thrips and Fungus gnat.	Nursery.
	Neoseiulus cucumeris	Broad mite, onion thrips, western flower and Plague thrips.	Flowers/ornamentals, greenhouse cucumbers, eggplants, capsicums, tomatoes, strawberries.
	Neoseiulus wearnei (=*N. californic*us)	Bean red spider mite, Broad mite, Two spotted spider mite.	Berry fruit, flowers/ ornamentals, greenhouse cucumbers, capsicums, eggplants, tomatoes, strawberries.
	Phytoseiulus persimilis	Two-spotted spider mite and bean red spider mite.	Strawberries, berry fruit, flowers /ornamentals, greenhouse tomatoes, capsicums, and eggplants.
	Stratiolaelaps scimitus	Fangus gnat, sciarid flies, shore flies, various thrips and soil pests.	Nursery herbs. Snakes/Reptiles.
	Typhlodromus occidentalis	Two spotted spider mite.	Nursery tree crops.
Insectary 2	Multiple species of wasps, beetles, lacewings and mites: *Aphytis lingnanensis*	Red scale and other armoured scaled insects, (oriental and oleander scales).	Citrus, passionfruit, olives, walnuts and roses, ornamentals such as palms and farns.
	Leptomastix dactylopii	Mealybug.	Citrus.
	Spalangia endius	Certain fly (such as house flies and stable flies).	In any areas where flies are pests.

Insectary companies	Commercial BCAs produced	Target pests	Target crops
	Trichogramma pretiosum	Heliothis, Cabbage moth (diamondback moth), European corn borer, corn earworm and cabbage looper,	Cotton, citrus, sweet corn, cabbage, tomato and tobacco.
	Trichogramma carverae	Codling moth, Oriental fruit moth, light brown apple moth and fruit stem borer (pecan stem girdler).	Tomatoes, capsicum, French beans, cut flowers, lettuce, pears, strawberries, grapes and apples.
	Typhlodromips montdorensis	Thrips (onion, tomatoes, melon and western flower), greenhouse whitefly and Silverleaf whitefly.	Gerbera, strawberry, chrysanthemum, and cucumber.
	Chilocorus circumdatus *Chilocorus baileyi*	Red scale, Oriental scale, Oleander scale, and white louse scale.	Used in enclosed and in orchard situations.
	Cryptolaemus montrouzieri	Mealybugs, Pulvinaria scales, cottony cushion scale and soft scales.	Orchards and vineyards, indoor and glasshouse plants. ornamental plants and flower buds
	Chrysoperla rufilabris	Whiteflies, mealybugs, mites, small caterpillars/larvae, green apple and brown citrus aphids, and thrips.	Citrus, greenhouses, fields, interior scapes, orchards, and gardens
	Mallada signata	Aphids (various species), Two-spotted mite, greenhouse whitefly, scales (various species), moth eggs, mealybugs and small caterpillars.	Greenhouses, tree and shrub crops.
Insectary 3	Single species of mite: *Phytoseiulus persimilis*	Two-spotted spider mite and bean red spider mite.	Strawberries, cut flowers and gardens.
Insectary 4	Six species of nematodes: *Deladenus siricidicola* (=*Beddinggiasiricidicola*)	Sirex Wasp.	Forestry.
	Heterorhabditis zealandica	Argentine scarab African black beetles, Argentine stem weevil, Red-headed cockchafer and black-headed cockchafer.	Pastures, and turfs
	Heterorhabditis bacteriophora	Black vine weevils.	Nurseries.
	Rhabditis necromena	Portuguese millipedes.	Urban and semi-rural areas.
	Steinernema carpocapsae	Armyworm/ cut worm, fleas and termite.	Farm, backyards and garden.
	Steinernema feltiae	Fungus gnat.	Horticulture industries, nurseries, the University research facilities, Department of Agriculture, AQIS and DPI.
Insectary 5	Single species of mite: *Phytoseiulus persimilis*	Two-spotted spider mite and bean red spider mite.	Strawberries, raspberries and cut flowers/ornamentals.
Insectary 6	Single species of wasp: *Trichogrammatoidea cryptophlebiae*	Macadamia nut borer.	Macadamias, lychees and longons.
Insectary 7	Three species of mites and bug: *Phytoseiulus persimilis*	Two-spotted spider mite, and bean red spider mite	Strawberries, berry fruit, flowers/ ornamentals, greenhouse tomatoes cucumbers, capsicums, eggplants and melons.
	Neoseiulus cucumeris	Broad mite, onion thrips, western flower and Plague thrips.	Flowers/ornamentals, greenhouse cucumbers, eggplants, capsicums, tomatoes and strawberries.
	Orius amatus	Onion thrips, Western flower thrips.	Strawberries, flowers/ornamentals, greenhouse cucumbers, and eggplants.

Table 4.4: Thirty-one commercial BCAs were available in 2011 and the year of which commercial BCAs production started in Australia.

Species Name	Orders	Taxonomic groups	Year of first production
Aphelinus abdominalis	Hymenoptera	Hymenoptera (11 wasp species)	2010
Aphidius colemani	Hymenoptera		2003
Aphytis melinus	Hymenoptera		1975
Aphytis lingnanensis	Hymenoptera		1979
Encarsia formosa	Hymenoptera		1992
Eretmocerus warrae	Hymenoptera		2010
Leptomastix dactylopii	Hymenoptera		1982
Spalangia endius	Hymenoptera		2010
Trichogramma pretiosum	Hymenoptera		1995
Trichogramma carverae	Hymenoptera		1990
Trichogrammatoidea cryptophlebiae	Hymenoptera		2000
Hypoaspis aculeifer	Mesostigmata	Acari or Acarina (7 mite species)	2001
Neoseiulus cucumeris	Mesostigmata		2003
*Neoseiulus wearnei (=N. californic*us)	Mesostigmata		2010
Phytoseiulus persimilis	Mesostigmata		1984
Stratiolaelaps scimitus	Mesostigmata		1998
Typhlodromus occidentalis	Mesostigmata		1988
Typhlodromips montdorensis	Mesostigmata		2008
Chilocorus circumdatus	Coleoptera	Coleoptera (4 beetle species)	1985
Chilocorus baileyi	Coleoptera		1989
Cryptolaemus montrouzieri	Coleoptera		1982
Dalotia (Atheta) coriaria	Coleoptera		2003
Chrysoperla rufilabris	Neuroptera	Neuroptera (2 lacewing species)	1995
Mallada signata	Neuroptera		1993
Orius amatus	Hemiptera	Hemiptera (1 bug species)	2010
Deladenus siricidicola (=*Beddinggia siricidicola*)	Tylenchida	Nematoda (6 nematode species)	1993
Heterorhabditis zealandica	Rhabditida		1999
Heterorhabditis bacteriophora	Rhabditida		1981
Rhabditis necromena	Rhabditida		2009
Steinernema carpocapsae	Rhabditida		1993
Steinernema feltiae	Rhabditida		1983

During the period 2011–2014 (after completion of the interviews) five new species of commercial BCAs were introduced into the Australian biocontrol market and the total number of species was 36. New species are:

1. *Eretmocerus hayati* (Hymenoptera) for Silverleaf whitefly,
2. *Aphidius ervi* (Hymenoptera) for Potato aphids,
3. *Diadegma semiclausum* (Hymenoptera) for Diamond back moth,
4. *Hypoaspis miles* (Mesostigmata) for Fungus gnat,
5. *Nesidiocoris tenuis* (Hemiptera) for Silverleaf whitefly.

This result shows that most of the commercial BCAs are produced by two large companies. Only three products are best sellers (selling a higher volume of products) in 2011. Over 40 years several commercial BCAs were introduced and discontinued in this market which indicates that this market is not stable.

The Australian commercial BCAs originated from six taxonomic groups. Hymenoptera (wasps) provides the majority of agents, followed by Acari (mites) Nematoda (nematodes), Coleoptera (beetles), Neuroptera (lacewings) and Hemiptera (bugs) respectively (Figure 4.2).

All the Australian insectary companies produce their products on-site. They sell their own products only. Initially they also sold products from other insectaries. They used to provide monitoring and consultancy services to growers but currently, the majority of them (5/7) do not. A few of them (2/7) have other IPM-related products for sale in addition to commercial BCAs. This result shows that initially when all the insectary companies were small all of them gave monitoring and consultancy services.

4.3.2.2 Industry size

This study attempted to describe the size of the industry in the following ways: number of people employed, gross sales, volume of insect production, crop area under commercial BCAs.

In terms of the employment of people including the seven insectary owners which were operational in 2011, there were only 43 full-time and about seven part-time people working in the entire industry with the number of part-time people varying with the season. The majority of the Australian companies (5/7) had 1–6 full-time people and only a few companies (2/7) employed more than ten people. The number of employees in the Australian insectary industry is very small.

The economic size of the Australian industry was measured by gross sales. The majority of the insectary owners (4/7) reported that their estimated gross sales were less than AUD$500,000 for the 2010–2011 financial year. A few of them (3/7) said that estimated gross sales were more than AUD$800,000. The estimated gross sales of Australian commercial BCAs produced by seven insectary companies were AUD$5–7 million for the 2010–2011 financial year. Thus the economic size of this industry was very small.

In terms of the volume of production the industry is growing. The majority of the insectary owners (6/7) said that their turnover has increased. A few of them (3/7) explained that the existing clients have an increasing agricultural farm size and are producing more crops so a greater volume of commercial BCAs is needed to keep pace with this growth. This result shows that even though the turnover is increasing, this is due to the same clients buying more commercial BCAs, rather than an increasing number of clients.

It would be useful for insectary business expansion to keep records of the land areas treated with mass reared commercial BCAs. The majority of the insectary owners (5/7) however thought it was too difficult to keep such records because they supply such a wide range of customers and the agents are used in a wide range of situations. One insectary owner reported that they can easily get that information from chemical companies. Some gave estimated values. This aspect of record keeping is clearly difficult or less important to them for their business.

4.3.2.3. Who purchases commercial BCAs in Australia?

It is important to know the customers for commercial BCAs. According to the seven insectary owners approximately 4500 clients (growers and other consumers) use commercial BCAs in 2011 in Australia and 99% of their products go to horticultural crops (apples, blueberries, citrus, macadamias, pears, stone fruits, strawberries, ornamental nurseries and vegetable crops) for pest control with 1% used for other purposes such as domestic, forest, pasture pest control or research. Thus this industry is horticulture based.

A few of the insectary owners (3/7) noted that organic growers were very small users of commercial BCAs. They said that organic growers depend on organically registered pesticides. Insectary owners also believed that most of these pesticides are not safe for beneficial insects and some pesticides are very disruptive to these insects. This reveals that organic growers are mostly non-users of commercial BCAs.

The Australian insectary industry does not currently export commercial BCAs. Biosecurity is a big issue in Australia as well as overseas and biological control agents are highly perishable. The majority of the insectary owners reported that delays in the supply chain cause deterioration of agent quality. Previously some of the insectary owners did export their products to Europe, New Zealand and South Africa. Only a few insectary owners (2/7) shipped their products overseas for research purposes. Thus the Australian insectary industry is based almost entirely on the domestic market.

4.3.2.4 Quality control of commercial BCAs in Australia

Product quality and quality control is an important issue for this business. To maintain product quality most of the insectary owners (4/7) followed the International Organisation for Biological Control (IOBC) guidelines as well as their own guidelines. Other insectary owners (3/7) followed only their own guidelines because of the local weather conditions and facilities. They also said that if they did not have good guidelines then their business would fail. Insectary owners addressed quality control by good communication with customers and visiting most of the growers that they supply with commercial BCAs to check product quality. Some of them (3/7) said that they re-established colonies from field collections after agents were released. Two others (2/7) measured biological characteristics they considered indicative of product quality such as fecundity, longevity, flight dispersal, and sex ratios. They all have contact with universities or State Departments of Agriculture or CSIRO researchers who are involved in biological control research. They aimed to produce not only high quality commercial BCAs but also sufficient quantities to be able to supply customers during seasonal peaks in demand. This result showed that the Australian insectary owners followed IOBC and their own guidelines to maintain product quality.

4.3.2.5 Marketing of commercial BCAs in Australia

Advertisement or promotion of any business is important. All insectary owners have their own website and they believed that the website is effective for advertising and promoting the sale of commercial BCAs. They also formed an association called ‘The Australasian Biological Control Association Inc.’ which has its own website with links to individual insectaries. They advertise through crop specific magazines, newsletters, field days, radio programs, mail outs, attendance at relevant crop seminars and make direct contact with the growers. A few of them (2/7) showed a negative attitude towards advertising through horticultural magazines. Most of the insectary owners (4/7) said that advertising is very expensive for them. The insectary owners made contact with the main research organisations, extension officers and crop consultants. Most of them are members of the IOBC, the Australian Entomological Society, related crop associations or crop consultant associations.

4.3.3 Main barriers in Australian insectary industry

This section presents results of all nine insectary owners' interviews. To establish an insectary company, owners had to face many barriers such as up-front cost, and a lack of knowledge and experience. All insectary owners (9/9) said the up-front cost of insectary set-up is as a major barrier to the industry. They gave an estimated dollar amount that was invested up-front to set-up their insectaries (Table 4.5). In addition, all insectary owners mentioned that was just an initial investment and the businesses needed some running costs. One of them reported:

> "Well, it was a new insectary so we had no customers, no money and no products. So set-up cost of a new insectary is one of the major barriers".

Table 4.5: The up-front cost of a new insectary by Australian owners (estimated dollar amounts).

Dollar amounts	No. of insectary owners
Less than AUD$100 thousand	1
AUD$100 thousand to AUD$499 thousands	4
AUD$500 thousands to AUD$1 million	2
More than AUD$1 million	2

The insectary owners also reported that knowledge and experience were key components of insectary establishment. One of them reported:

> "I don't think it is the sort of industry that lends it to 'just saying here is a large sum of money just go and build an insectary' because you need knowledge and knowledge is not always easy to get within a short period of time".

The majority of the insectary owners (8/9) had strong academic backgrounds in entomology and the remaining owner had extensive work experience in this area. All had faced many difficulties in establishing and maintaining their businesses, including problems with starting insect cultures, harvesting, packaging, distribution, contamination and maintaining the host populations (insects and plants). Often hosts are more expensive and challenging than rearing the actual commercial BCAs. Some species are used seasonally but it is necessary to maintain them year round. It is clear that the up-front cost for the establishment of an insectary, knowledge and experience are major barriers.

The difficulty in bringing a new species of commercial BCA into this market was another major barrier. All insectary owners realised that it required significant amounts of money, technical knowledge and time, regardless of whether this new biological control agent entered the commercial market or not. A few of them (3/9) mentioned that they have collaborative projects with State Departments of Primary Industries (DPI) and/or Agriculture. In addition there are a few entomologists working on commercial BCAs in either Departments of Agriculture or universities in Australia. The majority of them (5/9) believed that input costs of commercial BCAs have increased over time but the market was very price sensitive so they were not able to raise prices as costs increased. Thus the cost to develop commercial BCAs is very high in terms of money, time and knowledge but the profit is relatively small.

Logistics was another important barrier for this industry because delays in transit might damage the commercial BCAs' quality significantly. All of the insectary owners said that their insectary companies were established in rural areas because they could not afford the significantly higher costs in major cities. One insectary owner reported:

> "I think it would have been quite difficult for us to do what we do, say in a major city because of the cost of land, cost of buildings and the cost of all that infrastructure would have been significantly higher and would have probably stopped us even getting going in the first place I think."

Being in rural areas is a disadvantage for getting products to the consumer. It takes extra time and their clients were based primarily in rural areas too. Some of the customers are out of the overnight postal delivery areas. The establishment of the insectary companies in the major cities is very expensive and faces some disadvantages as a rural industry.

Most of the insectary owners (4/9) reported that location is important in terms of climate such as temperature and humidity. If the climate is favourable for commercial BCAs production in one area then the cost of product development will be lower than the other areas that may not be as suited for that production. Thus the insectary industry establishment in a particular location depends on the climatic condition of that location as well as the geographical location in the country as a whole.

Often interstate biosecurity creates barriers for this industry. The   insectary owners (3/9) perceived that due to the interstate biosecurity for Queensland fruit fly, sometimes their clients had to use chemicals and then they could not use commercial BCAs. They also could not send soil and plant materials into different states due to interstate biosecurity and thus create a complexity for this industry's expansion.

Sometimes contamination of the rearing system and natural disasters such as floods disrupt production, but only 2/9 reported loss of clients. Only one said that Genetically Modified (GM) crops such as GM cotton had a negative impact on his company because one of the commercial BCAs (*Trichogramma pretiosum* Riley) is no longer used in the cotton cropping system for control of *Helicoverpa* spp. (Lepidoptera: Noctuidae). Another barrier for this industry is competition. One insectary owner reported that:

> "The Australian insectary owners' biggest concern is competitors whether it is national or international."

On the other hand, another insectary owner stated:

> "Everyone should try to do work together without being antagonistic to each other".

The insectary owners may be concerned about direct competition. They were cautious to train people for insect rearing systems or technical support to the growers. Often one company produces the same product that another company produces and uses the same market to sell their product which indicates that direct competition exists among the insectary companies because the Australian market is entirely domestic and not big enough.

There is a lot of history in this industry that has not been documented. One insectary owner said:

> "I think that there is a huge amount of work and experience in this industry that's not documented scientifically in journals".

He also said that they had to write reports for research agencies when they do research with support from such an agency. These are accessible but not publicly available. Insectary owners have hands on experience because of the application of the products in the field, their understanding of IPM, monitoring and all the interactions that are happening in the field. It was also reported that all the companies have manuals for their production systems which are used by their employees. These manuals are built on continually as they learn more and more about rearing commercial BCAs. However, for the success of the business there is a certain level of secrecy. The insectary owners have hands on experience that is either not documented or not accessible. Perhaps the insectary business is somewhat confidential because of this commercial sensitivity.

Insectary owners believed that the patenting process is expensive and requires a certain level of experience and time. They also believed that they have to disclose their technologies to apply for a patent which makes them more unprotected. Instead they think that the complexity of their production systems and other technologies offers them more protection than a patent. In Australia, only nematode commercial BCAs are patent protected but the remaining commercial BCAs are not. The commercial BCA rearing methods and other associated technologies for their use may be the main subjects for the patent because free living, naturally evolved organisms cannot be patented.

4.3.4 Main driving factors in Australian commercial BCAs' market.

Driving factors influence growers to adopt new technologies. All the Australian insectary owners (9/9) believed that there are some driving factors which influence growers to switch from conventional (chemical) control to IPM. The driving factors are discussed below:

Insecticide resistance is one of the major driving factors. All insectary owners (9/9) said that when an existing pest management system is no longer working because an insecticide has failed then growers made changes and switched to IPM. For example the two-spotted spider mite (*T. urticae*) became resistant to many insecticides in Australia during the 1980s. Afterwards IPM was developed which incorporated a commercial BCA (*P. persimilis*) and many growers use this to control this pest. This shows that insecticide resistance influences growers to adopt commercial BCAs in an IPM program.

Sometimes pesticide withdrawal or cancellation is the driving factor to switch from conventional control to IPM according to a few of the insectary owners (2/9). For example, Endosulfan has been withdrawn from the Australian chemical insecticide market. This insecticide was used in many crops to control the key pests. This may lead growers to find alternatives such as the commercial BCA, *Anastatus* sp. (Hymenoptera: Eupelmidae) a parasitoid of the fruit spotting bug that is under development.

Often health and environmental safety concerns may be one of the major drivers. Most of the insectary owners (4/9) believed that sometimes growers poison themselves and they do not want to use pesticides anymore because they have made themselves sick. A few of them (2/9) pointed out that just general increasing environmental concerns cause growers to adopt commercial BCAs. One insectary owner said that some growers genuinely want to reduce pesticides, but they are relatively few and probably are the more forward thinkers so health and environmental safety concerns can cause forward thinking growers to switch from chemical control to IPM and thus incorporate commercial BCAs into their IPM program.

The effectiveness of the commercial BCA is an important factor for adoption. A few of the insectary owners (3/9) believed that a commercial BCA is an effective alternative, fits in with the growers' other practices, and is relatively easy to apply.

The relative cost of BCAs compared to chemical control is another important factor. A few of the insectary owners (2/9) said that commercial BCAs are relatively cheap if compared with chemical insecticides. Sometimes using chemical insecticide is becoming very expensive. Growers want to try using commercial BCAs as an alternative cheap option. This study did not attempt to compare the cost of commercial BCAs and insecticides cost because information was not available.

Often a pest management consultant's advice is a very good driver. A few of the insectary owners (2/9) pointed out that pest management consultants can facilitate the sales of commercial BCAs. Sometimes better education by a consultant about IPM and commercial BCAs can changes growers' perceptions about pest control.

One insectary owner pointed out that generational shift is very much behind IPM. Younger growers may be more interested to try a new technology than older growers. He said that there were quite a lot of younger growers taking over the farm management from elderly parents (who have run the farm traditionally for a long time) and move to IPM.

Often overseas growers adopt commercial BCAs and this may be encouraging to domestic growers. Sometimes growers may travel overseas and actually see greenhouse growers in Europe or the USA, some of whom are using IPM and incorporated commercial BCAs in their IPM program. One insectary owner said that they were encouraged to try IPM when they returned home. Overseas travel influences growers to adopt commercial BCAs because physically they saw that commercial BCAs work and are very effective.

4.3.5 Opinion and recommendations by the Australian insectary owners

The Australian insectary owners (9/9) said that several factors are important for this business. The effectiveness of commercial BCA is an important factor emphasised by most of the insectary owners (4/9). One insectary owner pointed out that it has to be reasonably priced and a few of them (2/9) pointed out that they need more products to manage the pests in a particular cropping system. In addition, location is another important factor in terms of logistics (8/9), climate (4/9) and insectary success or failure as a business (5/9). This shows that the effectiveness of commercial BCAs is one of the major factors but economics and location are also important for business expansion. There are more commercial BCAs needed to control the pests in a particular cropping system.

The Australian insectary owners reported that the Australian pest control market is heavily dominated by pesticides. Citrus was the first IPM crop and it had great success, but currently there are many effective new generation chemical pesticides available for citrus pests. In addition, all of the insectary owners believed that selective pesticides are very good but the problem is how growers used them. They also pointed out that some selective insecticides may have some side effects on biological control agents. However, all insectary owners were very optimistic about this industry's future.

The Australian insectary owners made the following recommendations to help the industry expand:

1. Growers need education regarding IPM because some fundamental changes in the growers' decision making process are needed and this will help the industry to expand (9/9).

2. Public education regarding IPM should start from primary school because consumers can drive this change from chemical control to IPM (9/9).

3. Government subsidies to support more research by insectary companies into the development of new commercial BCAs (9/9).

4. Government can help to introduce new rules or modify existing rules for growers to reduce the use of pesticides (6/9).

5. The supermarkets are big drivers that could promote produce grown using IPM (8/9). There is a need to introduce an IPM logo for fresh produce (4/9).

4.4 Discussion

Over four decades, the Australian insectary industry has expanded from one company and one commercial BCA to five companies and 36 commercial BCAs in 2014. Two decades after the establishment of the first insectary, the industry expanded rapidly based on *P. persimilis* that controls two-spotted spider mite (*T. urticae*). The two-spotted spider mite has a long history of pesticide resistance development both in Australia and worldwide. In Australia, multiple pesticide resistance in *T. urticae* has been reported during the early 1970s (Unwin, 1973; Edge and James, 1982, 1986; Herron et al., 1993; Herron et al., 2001).

From this investigation, it has been clearly revealed that out of nine insectaries four initially produced *P. persimilis*, to control two-spotted spider mite which is a generalised pest in many crops and developed resistance to multiple pesticides. There was no option other than the use of the cosmopolitan *P. persimilis* and it remains the leading commercial BCA in the Australian market for a number of insectary companies' establishments.

A possible reason for this period (1970–1999) of rapid expansion of insectary industries around the world were that many pest insects had developed resistance to insecticides during that period, and the difficulties of bringing a new insecticide into the market (Warner and Getz, 2008; van Lenteren, 2012). In Europe pesticide reduction was the main driver for the expansion of the insectary industry because of consumers' demands, legislation and withdrawal of hazardous pesticides (Cannell, 2007). Insecticide resistance and other factors such as greenhouses were also driving factors for the expansion of the European insectary industry. When the Australian insectary industry expansion stopped due to the lack of markets, there were no other drivers in Australia. Therefore, only seven commercial companies were operating by 2011. The number was reduced in 2014 by amalgamation of 2 small insectaries with larger ones. Currently five insectary companies are operating on a commercial scale.

This study revealed that pesticide withdrawal or cancellation of pesticide registration was a driving factor. One commercial BCA, *Anastatus* sp. of fruit spotting bugs, *Amblypelta* spp. (Hemiptera: Coreidae) is under development in Australia because an effective broad-spectrum insecticide (Endosulfan) was withdrawn not only from the Australian market but from the global market (Huwer et al., 2011). This result is consistent with other studies that when Endosulfan was withdrawn, a major driving factor was found in Europe and North America (Warner and Getz, 2008; van Lenteren, 2012).

Many authors stated that augmentative biological control or using commercial BCAs is expanding. There is a rising number of available species and commercial suppliers of biological control agents and as a result the insectary industry is expanding around the world (Parrella et al., 1992; van Lenteren, 2003a; Pilkington et al., 2010). A few of the researchers argued that it is not increasing. The reason given is that commercial BCAs when released were usually less effective because of certain ecological limitations. In addition, they were more expensive than conventional insecticide applications (Collier and Steenwyk, 2004). In practice, the commercial insectary industry is increasing around the world and this suggests that this view is not widely supported (Parrella et al., 1992; van Lenteren, 2003a; van Lenteren, 2006; Pilkington et al., 2010). Is the Australian industry growing? The answer may be yes because insectary owners' turnover is increasing and in terms of volume, production is increasing. However, no new clients have been attracted and this growth does not have a positive impact on the growth of the industry expansion. Without new clients, industry expansion does not occur. This study does not support Collier and Steenwyk's (2004) argument because the Australian insectary owners reported that the commercial BCAs are reasonably priced and cheaper than chemicals. They also reported that BCAs are effective. Other factors may involve a lack of growth of this industry in Australia. These are discussed below:

In terms of employment, this industry is still very small. The Australian industry employed fewer than 60 people and only two companies employed more than ten people. In comparison, the European insectary industry had over 750 employees in 1997 (van Lenteren et al., 1997). In 2011, the number of employees is much larger and 20 large insectary companies (large = employed more than 10 people) are located in Europe. The largest company in Europe employed 600 people in 2011 (van Lenteren, 2012). In North America, the 22 insectary companies employed approximately 200 employees but there are unknown numbers of small privately-owned insectaries which serve citrus and other orchards. In addition, many species of commercial BCAs are imported from Europe and several other countries (Warner and Getz, 2008). Perhaps, the Australian insectary companies could not afford to hire more employees because most of the insectary companies produce only one to three commercial BCAs and the turnover is not enough to warrant the employment of more people.

In Australia, two of the large insectary companies produce most of the commercial BCAs and six taxonomic groups provided 31 species of commercial BCAs in 2011. Hymenoptera occupied the first position followed by Acari, Nematoda, Coleoptera, Neuroptera and Hemiptera respectively. Worldwide ten taxonomic groups provided commercial BCAs, a total of 242 species. Four taxonomic groups provided the most commercial BCAs for worldwide pest management and Hymenoptera (wasps) leads these groups followed by Acari (mites), Coleoptera (beetles) and Hemiptera (bugs) respectively. Nematoda (nematodes) and Neuroptera (lacewings) occupied the fifth and sixth position respectively (van Lenteren, 2012). The importance of Hymenoptera and Acari in Australia followed the world trend, probably because the desirable traits of these agents are just as useful in Australia as elsewhere (Bigler, 2006; van Lenteren, 2012). The last four in Australian taxonomic groups did not follow the world trend because some species of these groups were not commercially available in other parts of the world. These biological control agents and their hosts (pests) are native species in Australia. Some of the predators are not host specific, for instance *C. montrouzieri* is a native species in Australia and a predator of mealy bugs and scale insects. This predator had been previously exported by an Australian insectary company around the world. Currently many insectaries worldwide rear this commercial BCA.

Product quality and consumer perception of product quality is a critically important issue in the commercial production of biological control agents (van Lenteren, 2000a, 2003b; Warner and Getz, 2008; Fielding, 2012). To maintain product quality for the commercial sale of biological control agents the International Organization for Biological Control

(IOBC) in Europe developed guidelines following global consultation (van Lenteren et al., 2003). This study revealed that there is no guideline for quality control of commercially produced biological control agents in Australia. However the insectary owners are aware of the importance of quality control and know there are IOBC guidelines for mass production of biological control agents. A few of the Australian insectary owners follow IOBC guidelines but most of them follow their own practices to achieve quality assurance. The Australasian Biological Control Association Inc. does not have enough economic resources to develop Australian guidelines appropriate to the local industry.

In 2011, the Australian market was dominated by three commercial BCAs; *N. cucumeris, Aphytis* spp. and *P. persimilis* based on the volume of production. These are the best-selling commercial BCAs but it does not mean that these will be the best-selling products in the future because the arrival of new agents can change the market significantly. For example, in greenhouse systems worldwide, 25% of the total sales revenue on commercial BCAs came from *E. formosa* (van Lenteren, 2007) followed by *P. persimilis* and *Amblyseius cucumeris* (Oudemans) at 12% but this division of agents changed significantly with the success of another phytoseiid mite *Amblyseius swirskii* (Athias-Henriot) and sales of this new species are said to be increasing in Europe and North America (Pilkington et al., 2010). This study did not attempt to further investigate this area.

The nematode commercial BCAs market is not large in Australia. One local company produces six species of nematodes in 2011 but on a very small scale. Even in Europe or in North America, the nematode market was not big enough to make more than a few nematode species available (Warner and Getz, 2008). Several researchers argued that additional research and customer education was necessary regarding nematodes (Stuart et al., 2006; Georgis et al., 2006).

In terms of gross sales the economic size of the Australian insectary industry was very small compared with the European and North American insectary industries. The global market values of commercial BCAs used in greenhouses was US$300 million and Europe occupied 75% of market value followed by North America (10%) (Cock et al., 2009). One of the largest companies in Europe has production and marketing in 45 countries and the North American industry has an estimated gross annual value of US$2–530 million at the wholesale level (Warner and Getz, 2008). The Australian industry has estimated gross sales well below AUD$10 million for the 2010–2011 financial year.

From the discussion above it is noticeable that the Australian insectary industry is far behind the European and American industries. This industry faces many challenges that hindered the growth of this industry. These are discussed below:

This study revealed that to bring a new species into the market required a huge amount of money and time. This industry by itself does not have the economic resources to bring in a new species. It is dependent on scientific research conducted by public agencies and universities in Australia. This type of research is limited by a lack of funding and the industry also gets very limited support for basic biological research that underpins the development of commercial BCAs. In North America, this type of applied research has been cut back over the past two decades (Warner, 2007). Recently (2012–2014), two large Australian insectary companies introduced five new species (www.goodbugs.org.au) in the Australian pest control market. One of them was *Eretmocerus hayati* which controls Silverleaf whitefly. This pest was introduced into

Australia and is a comparatively new pest in different crops such as cotton (broad acre crop), and fruit and vegetables (horticulture). It developed resistance to multiple insecticides and no parasitoids are available to control this pest effectively in Australia (DeBarro and Coombs, 2009). A collaborative research program with insectaries, government organisations and other industries introduced this commercial BCA in the Australian pest control market (Bugs for Bugs, 2015). A multi-target approach (a pest that damages multiple crops or a commercial BCA that controls multiple pests) may be essential for collaboration which is an important way to overcome this barrier.

Collaboration is also essential within this industry in terms of marketing and sharing information. It is necessary to share information with overseas insectaries and scientific communities so that they can provide basic and applied research support which is essential for insectary expansion (Warner and Getz, 2008). Collaboration is also important for successful implementation of commercial BCAs because it is applied in a system which is multidisciplinary. This system needs to be favourable for the commercial BCAs to be effective.

Often contamination can disrupt the rearing system or natural disasters, such as floods, cause a scarcity of commercial BCAs. As a result, growers switch from IPM to conventional pest management methods. In Australia, only two companies supply multiple agents and if those companies are unable to provide the product when needed, growers must use an alternative even if their first choice would be to use commercial BCAs. This is another limitation in the Australian insectary industry. Perhaps this limitation can be overcome. One may be able to supply agents when the usual supplier cannot.

The Australian insectary owners identified as a main barrier the insectary set-up and business running costs. They pointed out that for at least one or two years they had to face major challenges because there were no clients to buy their products. Most of them could not produce cost-effective products and attract more clients because of their small infrastructure. Often this industry faces challenges that are identified by other researchers such as extra costs for the contamination of rearing systems and maintenance of the host population (insects and plants). Often the host population became more expensive than rearing the actual commercial BCAs (Penn, 1998; Warner and Getz, 2008). Perhaps they can reduce production costs by following multi-target approaches such as producing multiple commercial BCAs from a single rearing host such as other insects, plants, soil, fruit and vegetables.

The size of the Australian insectary industry was stalled by several other factors such as the Australian cropping system (broad acre, greenhouse and organic) and market destination (domestic and export). The market destination can be influenced by logistics and biosecurity problems. These are discussed below:

In Australia, protected cropping systems represent a much smaller proportion of the total crop areas in Australia compared with Europe or the USA, so presumably the bulk of Australian sales must be for use on open field crops. In the greenhouse system, pests reproduce faster because of the suitable environmental conditions. This needed high pesticide frequencies. As a result pests developed resistance to pesticides very quickly and growers search for alternatives such as IPM and commercial BCAs (van Lenteren and Woets, 1988; van Lenteren, 2000a). In broad acre cropping systems perhaps commercial BCA adoption is not cost effective. Insectary owners also said that the number of growers is also very small in Australia. Previous studies revealed that in many broad acre cropping systems IPM is not well developed or IPM is not adopted or little-adopted by broad acre cropping growers for pest management in Australia (Williams and Il'ichev, 2003; Horne et al., 2008). Currently protected cropping is a rapidly expanding industry in Australia (Taig, 2009). This may be a driving factor for this industry expansion in the future.

Insectary owners reported that a few Australian organic growers use commercial BCAs. The national and the International Federation of Organic Agriculture Movements (IFOAM) guidelines recommended the use of parasitoid, predator and microbial commercial BCAs for pest management in organic farms (Zehnder et al., 2007). In Australia a previous study reported that organic growers may not be aware that most organic pesticides are killing beneficial species and need to be cautious that they are not using more disruptive pesticides (in terms of effects on beneficial species) than conventional growers. The reliance on pyrethrum and BT is not sustainable, is expensive, and certainly not desirable in terms of pest management (Horne, 2007). Some commercial BCAs have broad host ranges and some are non-native which may cause concern over non-target-effects (Speiser et al., 2004). Presumably, organic growers use biopesticides that are specifically registered for organic farms or they use ecologically based pest management like conservation biological control which leads to higher natural enemy diversity and abundance on organic farms (Furlong et al., 2004; Macfadyen et al., 2009). In addition, augmentation of commercial BCAs with the combination of other methods in organic farms may cause the commercial BCAs to be less effective than stand-alone use (Zehnder et al., 2007). Perhaps organic growers accept some levels of crop damage because their clients accept certain levels of blemishes on fruit and vegetables and are paid a higher premium for organic produce.

For any industry expansion, market destination (domestic and international) is an important factor. The Australian insectary industry is confined within the domestic market. Insectary owners reported that previously they exported commercial BCAs into several countries but they stopped because of huge biosecurity issues both in Australia and overseas. Logistics is another problem because live organisms need good access to transport systems otherwise any delays can cause degradation of commercial BCAs' quality (Warner and Getz, 2008). Interviewed insectary owners also perceived that logistic and interstate biosecurity created problems in the domestic market. Long-distance transportation (because Australia is a large country) and interstate movement of host materials (soil and plant materials) could be a real problem. To overcome biosecurity and logistic problems perhaps the Australian insectary companies can establish production facilities in different states and overseas like European insectaries (Warner and Getz, 2008).

Growers are the end users of the commercial BCAs. The Australian insectary owners pointed out that to implement commercial BCAs growers need education about IPM and commercial BCAs. Growers are largely influenced by pest management consultants and extension agents. Many researchers have pointed out that failure to adopt IPM or commercial BCAs largely depends on pest management consultants and extension agents because often they undercut growers confidence on commercial BCAs (Malone et al., 2004; Warner, 2007; Kaine and Bewsell, 2008; Warner and Getz, 2008). Interviewed insectary owners recommended that pest management consultants and extension agents need education about IPM and commercial BCAs.

Promotion of commercial BCAs is a crucial part of this industry. It has stuck to its own website because the industry does not have enough economic resources for massive advertisement. A few of the insectary owners stated that crop specific or horticultural magazine advertisements are least effective, whereas in other countries such as in Europe, the primary sources of information for growers regarding commercial BCAs are agricultural journals (local and national), other growers, and extension services; secondary sources are TV, radio and the internet (Moser et al., 2008).

Insectary owners were happy as small operators because they reached a certain level of expansion. They have viable businesses and do not want further expansion because most of the companies were operating on very small scales by one person. It will be challenging for them to manage a wide range of clients.

This industry has plenty of information or data on commercial BCAs not published in a scientific journal. Perhaps the insectary owners do not have time to publish or for commercial secrecy. Often commercial insectaries have information about unsuccessful commercial BCAs but that information remains unpublished. However, this information may be useful for a potential new insectary owner or augmentative biological control researchers for their research. Perhaps this may be one of the important impediments for the expansion of this industry.

Direct market competition exists in the Australian insectary industry. Insectary owners were very concerned about direct competitors whether it was national or international. In Australia, several companies offer the same products to the same market and perhaps the same customer base. Basically, the Australian insectary industry is very protective in terms of commercial secrecy. They were cautious to train people or keep secret their rearing information because it will be risky for their business. Other researchers described how the insectary companies have little protection except to keep secret their production and not to facilitate competition (Cock et al., 2010). Pesticide research and development is protected by international laws that give security of the intellectual properties to the chemical companies that develop a new chemical pesticide (Javier et al., 2010). This direct competition might be causing price competition or commercial BCA's quality degradation. Perhaps this may be one of the major barriers for this industry expansion.

Patents are essential for any commercial production. In Australia, only nematodes have patent protection. The remaining commercial BCAs are not patent protected primarily because of the insectary owners' perception towards the patenting process. In other places such as Japan, USA and Europe most of the commercial BCAs are patent protected. Often they give licences to the secondary insectary companies and expand their business. One of the European insectaries, Koppert which is located in the Netherlands is the applicant of 28 patents including a few commercial BCA rearing methods and other information from Australia (Javier et al., 2010). This suggests that perhaps this company will give licences to one of the Australian insectary companies and expand their business in Australia as well. This result showed that the patent process is costly. Spread over its entire 21 year life, an Australian standard patent for a single mechanical invention typically costs in the vicinity of AUD$30800 (including 10% Goods and Services Tax) (www.wadesonip.com.au/patent-attorney-services/patents/patent-costs/). To manage the patent costs the large insectaries could give licences to the small companies because the large insectaries have the required resources for the patent process. The lack of patents has constrained commercialisation and integration of commercial BCAs into crop protection.

Finally, the Australian insectary owners made recommendations on several aspects. They believed several options are available that could favour the expansion of this industry.

Firstly, public awareness can change the whole scenario and favour expansion of this industry. Secondly, to create a targeted collaborative research program between this industry and the government so that it can favour the expansion of the industry. Thirdly, this industry is very specific and the market is also very specific and primarily dependent on growers' decisions. Therefore it is necessary to educate growers about IPM and commercial BCAs. Finally, an IPM logo for fresh produce will favour industry expansion by increasing public awareness. In many overseas countries consumers are encouraged to ask for products displaying appropriate labels, for example, in New York, IPM produce is now labelled (Sansavini, 1997; Cameron, 2007). Similar recommendations came from previous work in Australia and other countries (Warner and Getz, 2008; Cock et al., 2010; Pilkington et al., 2010; Gurr et al., 2010; van Lenteren, 2012). If these recommendations become effective then perhaps this industry will expand.

4.5 Conclusions

The Australian commercial insectary industry represents a very small economic sector in Australia. Based on insecticide resistance this industry expanded for a certain period. Then the industry became static because no other driving factors exist in the market.

Business protectiveness is one of the major barriers of this industry expansion. It needs collaboration and patents to overcome several barriers that are currently facing this industry such as insectary set-up cost, lack of research support, bringing a new species into the pest control market, logistic problems, interstate biosecurity problems and direct market competition.

The insectary owners made some recommendations and need to take these recommendations into consideration. This study revealed that they needed some further research in several areas such as promotion of commercial BCAs, organic cropping systems, market competition, collaboration and protectiveness.

Chapter 5: Researchers' interviews

The citrus pest management researchers were interviewed to help to understand the views of the researchers about the use of commercial biological control agents (commercial BCAs) and the state of the Australian insectary industry. Some of the researchers are currently working on citrus pest management and others have previous experience of this. The reason for this selection was that the citrus industry is the case study chosen as it was the first industry to use commercial BCAs (Chapter 1). The findings from these interviews are described below:

This chapter addresses the specific Objective 2 (Chapter 1 and 3, Figure 3.2):

> To identify the key barriers to augmentative biological control (commercial BCAs) and the different factors that influence these barriers from perspective of the researchers involved.

The chapter describes the researcher's perspectives of the barriers that have impeded the growth of the Australian insectary industry, opportunities for public policies to encourage industry growth and key obstacles which made augmentative biological control (commercial BCAs) unable to fulfill its potential in Australia.

5.1 Introduction

Research is a crucial part of the commercial insectary industry and researchers are an important group who are conducting research on commercial BCAs. They document and develop interpretations which are directly related to the industry. They are the key informants to address the scientific questions of commercial BCAs. In North America, the surveyed researchers who are involved in augmentative biological control address the applied scientific questions of commercial BCAs (Warner and Getz, 2008). They are not only important for the scientific issues but successful implementation of commercial BCAs as well. Researchers spend a lot of time in the field with the growers or working closely with the insectary owners. Researchers have developed methodologies in which they and the growers work together to develop novel technologies and create a much higher probability for adoption of technologies by growers (Williamson, 1998).

Nevertheless some researchers do not believe that augmentative biological control actually works. They believe that certain ecological limitations, such as an environment, which is not favourable for commercial BCAs makes them less effective (Collier and Steenwyk, 2004). Others stated that there are plenty of examples of successful practical augmentative programs around the world (van Lenteren, 2012). An example is the control of the two-spotted spider mite *Tetranychus urticae* Koch in strawberries with *Phytoseiulus persimilis* Athias-Henriot and *Neoseiulus* (=*Amblyseius*) *californicus* (McGregor) in California, Florida, Israel, Australia, South Africa, Spain and Italy (van Lenteren, 2006). However, to implement commercial BCAs as augmentative biological control agents, researchers must be aware of farmers' problems and perceptions. Researchers need to deal with all the pests in a crop but often they focus on a single pest. It is not possible to study the commercial insectary industry without understanding the perceptions of researchers involved in augmentative biological control (Olsen et al., 2003; Horne et al., 2008).

5.2 Methods

During 2012–2013, nine (9) researchers (who are experienced with Entomological research including citrus pest management in Australia) were interviewed by the author.

Before conducting interviews ethics approval was granted by the University of Sydney Human Research Ethics Committee (Approval Protocol No: 14675, 19 April 2012).

The citrus pest management researchers' publications were searched to identify the authors. Then they were recruited by their profile search through different institutions, namely the universities, state departments and the CSIRO. A list of 14 citrus pest management researchers were compiled who are either currently active in citrus pest management research or had previous experience. The author did not try to find more researchers because of time constraints. Each researcher was then contacted and interviews were conducted until the author judged that no new information or views were being expressed which indicated that data saturation had occurred. Nine were interviewed who were from different states in Australia. Seven researchers were from government organisations, one from a university and one was an insectary owner from the insectary industry. This insectary owner was interviewed twice; first as an insectary owner and second as a citrus pest management researcher because he has spent a long time researching citrus pest management.

All participants were contacted initially by telephone or email to confirm their willingness to be involved in this survey. Each contact was brief, personalised, and confidential and they were informed that only aggregated research results will be used. Each participant received a Participant Information Statement (PIS), consent form and cover letter (Appendix 2).

Nine semi-structured interviews were conducted, four in person (face-to-face) and five by telephone because they were located a long distance away from Sydney. The interviews were conducted flexibly to allow responses and follow-up questions. Initial questions were open-ended, with follow-up questions seeking detail on areas of interest to the interviewer that were brought up by the respondents (citrus pest management researchers). An interview pro-forma was developed prior to the interviews and areas covered were General information, Integrated pest management (IPM), Augmentative biological control (commercial BCAs) and the Australian insectary industry (Appendix 8). In this study, qualitative data were collected. The interviews were recorded (audiotaped), with an average length of 40 minutes and then transcribed using Express Scribe software (Express Scribe 5.55© NCH). Then the transcribed text of the appropriate interview was sent to each interviewed researcher for approval.

<u>Analysis of citrus pest management researchers' interviews</u>

Theme analysis was conducted and followed the same procedure as described for the Chapter 4 interviews. Researchers' interview pro-forma (Appendix 8) was topic based with questions grouped into different topics of inquiry namely:

1. General information,
2. Integrated pest management,
3. Augmentative biological control,
4. Australian insectary industry.

According to the structural coding the interview responses were coded using NVivo 10.0 text analysis software (Namey et al., 2008). Each topic was coded such as: GINFO for General information, IPM for Integrated pest management, ABC for Augmentative biological control and AIIND for the Australian insectary industry. Within a topic, each question was given a code name which contained a prefix for the topic and an identifier for the question such as: GINFO_research experience, IPM_define ipm, ABC_naturally occurring BCA. The full lists of these codes are shown in Table 5.1 under the headings: General information, Integrated pest management, Augmentative biological control and the Australian insectary industry.

Table 5.1: Interview code (node in NVivo) descriptions. Four topic codes and each topic code has a group of question codes.

Code	Code descriptions
1. Code: GINFO	**General information**
GINFO_research experience	Researchers' research experience.
GINFO_collaborative research	Collaborative research with insectary industry.
GINFO_future research	Future research on commercial BCAs.
2. Code: IPM	**Integrated pest management (IPM)**
IPM_define ipm	Researchers' view about IPM.
IPM_practicing ipm	Researchers' view about practicing IPM by growers.
IPM_switch ipm	Factors influence growers to switch from conventional control method to IPM.
IPM_tendem use	Tandem use of selective pesticides and commercial BCAs in IPM.
IPM_implement ipm	Opinion about the implementation of IPM.
3. Code: ABC	**Augmentative biological control (ABC)**
ABC_naturally occurring BCA	Are naturally occurring biological control agents (BCA) enough to control the pests?
ABC_factors favour ABC	Factors favour augmentative biological control.
ABC_not use commercial BCAs	Why growers do not use commercial BCAs?
ABC_growers uptake of commercial BCAs	How growers influenced by the state of the commercial insectary companies?
ABC_ABC is poor or valueless	Importance of augmentative biological control in pest management.
4. Code: AIIND	**The Australian insectary industry**
AIIND_factors affect expansion	Which factors affects the Australian insectary industry?
AIIND_opportunites exist	What opportunities exist for commercial BCAs?
AIIND_current rules and regulations	Opinion about current rules and regulations.
AIIND_quality issues	Working with researchers for quality control.
AIIND_GM crops	Opinion about GM crop's impact on the Australian insectary industry.

As described in Chapter 4 the coded data were then categorised or classified according to the emerging themes where the meaning of responses was consistent and unambiguous. Through this process, all examples of each theme were pulled together so that the results could be interpreted for that theme.

5.3 Results

The majority of the interviewed researchers were male (6/9) and remaining were female (3/9). They have an average of 22 years research experience (in this context entomological research including citrus pest management research experience) which included an average of 17 years of citrus pest management experience. Most of them (5/9) were directly and a few (2/9) were indirectly involved in collaborative research with commercial insectary companies. Most of them (6/9) were interested in doing research with commercial insectary companies and a few of them (3/9) have potential projects under consideration.

The results are given below under the five themes that were identified by the analysis of interview responses. The five key themes became the subheadings for the results (Table 5.2).

Table 5.2: Themes identified from the citrus pest management researchers' interviews.

Themes	Name of the theme
5.3.1	Citrus pest management researchers' perceptions of IPM.
	5.3.1.1 Reasons for use of pesticides.
	5.3.1.2 Promoting IPM.
5.3.2	Citrus pest management researchers' perceptions of commercial BCAs.
	5.3.2.1 Naturally occurring biological control agents.
	5.3.2.2 The importance of commercial BCA in IPM.
5.3.3	Citrus pest management researchers' perceptions of the main barriers which influenced Australian growers.
5.3.4	Citrus pest management researchers' perceptions of the main driving factors which influenced Australian growers.
5.3.5	Citrus pest management researchers' recommendations for the expansion of the industry.

5.3.1 Citrus pest management researchers' perceptions of IPM

Integrated pest management carries quite different meanings for different groups of researchers. All interviewed researchers believed that IPM is very broad and is a holistic approach which involves the use of a combination of different approaches or tools. A strategy is developed with a clear understanding of the biology of the system and the impact of any of the treatments, whether chemical or not. The ultimate goal should be to maximise the productivity of the cropping system with minimum reliance on pesticide application. This result shows that researchers defined IPM as a broad and ecologically based approach which minimises the use of chemical pesticides.

Implementation of IPM depends on the components or strategies of IPM that are practiced by the growers. Almost half of the researchers (4/9) said that the growers' practice of IPM covered a wide range of activities. A low level of IPM implementation (also called chemical based or tactical IPM) was characterised by monitoring pest populations followed by insecticide application according to the monitoring. A high level of IPM (also called strategic IPM) was ecologically based where pesticides were seen as the last resort. A few of them (3/9) pointed out that the level of implementation of IPM depends on the cropping system, pests and natural enemies of the system. The reasons for the use of pesticide and promoting IPM are discussed below under the two sub-themes:

5.3.1.1 Reasons for use of pesticides

Pesticides were considered unavoidable when pest populations became completely out of control. The majority of the interviewed researchers pointed out that in some cases it is useful to use pesticides to bring the population down to the level that commercial BCAs can manage. One of them said that in some cropping systems, with their current knowledge about the pest system, there was no IPM developed that growers can use. An IPM program may require some pesticide use and IPM is not available for all the cropping systems as well as all the pests.

For the export market, often growers need to use pesticides because of the need for blemish-free citrus. The majority of the researchers pointed out that once a grower was producing very high quality and blemish free citrus in terms of external appearance, they require an economic threshold (ET) that is simply incompatible with IPM. The broader more ecologically based IPM system is becoming increasingly difficult to rely on for pest control and growers need to use chemical pesticides for the export market. Often the economic threshold for export is not compatible with IPM. In other words, often IPM could not control the level of cosmetic damage for the export market.

Many growers were not actually aware that biological controls were working to suppress pest populations. One researcher reported that growers treat their farm with insecticide for a new pest incursion and unwittingly disrupt the existing IPM system. Growers lose awareness of the fact that the IPM approach is actually very worthwhile. This indicates that growers' awareness is important because unwittingly they disrupt the existing IPM systems and increase the secondary pest problems.

In terms of growers' background, one of the researchers said that most of the growers come from an insecticide background and historically they used only insecticides for pest management. For them to adopt an IPM approach means monitoring the pest populations and then applying pesticide accordingly which influences the implementation of IPM.

Selective insecticides are successfully working with commercial BCAs. Interviewed researchers stated that selective insecticides can help to change the pest dynamics in a cropping system. One of them said that:

> "Where selective pesticides have compatibility with the biological control agents then there is no reason not to use those at the same times."

The majority of the researchers (6/9) believed that it is necessary to choose insecticides carefully so that they have sufficient efficacy on the pests. Making informed insecticide choices are those based on a set of considerations as they know that the selective insecticides are only useful against one or two groups. Most of the researchers (5/9) believed that selective insecticides may be benign on several groups of key beneficial insects but generally do still have significant toxicity to other groups of beneficial insects. A selective insecticide is good but it is necessary to be cautious when chosen. It can have a negative impact on beneficial insects and may kill some of them or change the insects' behaviour or effectiveness.

5.3.1.2 Promoting IPM

The majority of the researchers (6/9) believe that supermarkets can help to promote better marketing signals by mentioning IPM products and perhaps minimal pesticide use. More awareness and information is given to the consumers by IPM certification. If consumers know the products have been produced using a well-run IPM system which is trying to minimise impact on the environment and maximise biological control, this would be a good thing. It would be very strong information for the consumers to make a decision about what type of system they want to support for buying produce. If consumers do not know anything about IPM they cannot make any decision based on it. A few of the researchers (2/9) pointed out that at the moment in Australia there is no or very little supermarket or consumers in general to demand IPM versus conventionally produced fruit and vegetables. It is very important to engage the public in any form of biological control, especially when the target pest needs to be controlled, not just within citrus orchards or other crops but in public areas, including backyards. One of them claimed that the crop industries do not promote the clean and green image to the consumer. Recent changes in the industry have placed greater emphasis on pesticide application than the promotion of IPM. This result reveals that crop industries need to be more IPM-focused than chemical based pest control. Supermarkets can play a major role in promoting IPM produced fruit and vegetables.

5.3.2 Citrus pest management researchers' perceptions of commercial BCAs

Interviewed researchers have different views about commercial BCAs. Often naturally occurring biological control agents are not enough and there is a need to release commercial BCAs. These are discussed below under the two sub-themes:

5.3.2.1 Naturally occurring biological control agents

Agricultural landscapes are generally a homogeneous and highly artificial environment. Interviewed researchers (3/9) generally expressed the view that natural enemies require different resources, complexities, and a high diversity of plants to satisfy their different nutritional and habitat needs and so will not work satisfactorily in an agricultural landscape. In most cases it just not possible to control the pests without some type of commercial BCA release because the agricultural system is different from the natural system.

In terms of climate, the agricultural system could not rely on the natural population of biological control agents. A few of the researchers (3/9) noted that often major heat waves or severity of winter temperatures were detrimental to the natural biological control agents. If they are suppressed to the point where they are not useful anymore then it is necessary to release commercial BCAs. This result indicates that climate has a large impact on natural biological control agents and positively influences the adoption of commercial BCAs.

The adoption of commercial BCAs was also influenced by the regional impact such as the influence of coastal areas. For instance, in coastal districts red scales, *Aonidiella aurantii* (Maskell) (Hemiptera: Diaspididae) in citrus crops are less important than in inland districts in Australia. This indicates that different regions have different pest pressure. A few of the researchers (3/9) noted that there are regions in Australia where particular biological control agents are just absent in citrus orchards because they have never been introduced. Most of the insect pests were introduced into Australia. They also said that natural biological control agents that are endemic in Australia are not useful for the control of these introduced pests because they have not grown up or adapted or evolved with the pest. So it is necessary to introduce commercial BCAs in the first place to tackle them.

Often the developmental timing of pests and their natural enemies' is very important. A few of the interviewed researchers (3/9) observe that often growers have been relying on naturally occurring *Aphytis* spp. to control red scales in citrus crops. However, it is not sufficient if it was not present at the right time, or the pest population was not at a suitable level to provide adequate control. Thus naturally occurring *Aphytis* spp. are not always useful to control pests (red scales) in citrus crops because of the developmental variation between the pest and the parasitoid. This influences the adoption of commercial BCAs.

Crop types and the production system are important and influence the uptake of commercial BCAs. One researcher was aware of countries where commercial BCAs are used most successfully in the covered cropping systems of vegetables, nurseries and other horticultural crops. But in outdoor cropping systems it would be costly, partly because of the cost of releasing and monitoring the commercial BCAs. The economic returns and the releases might be an economic limitation. This result indicates that the limitation of the adoption of commercial BCAs in outdoor cropping systems may be mainly for economic reasons.

Another interviewed researcher noted that by strategically releasing commercial BCAs, there can be acceleration of the natural population and thus help to achieve target levels of pest suppression during the season.

5.3.2.2 The importance of commercial BCAs in IPM

In terms of IPM tools, the majority of the researchers (7/9) believed that commercial BCA is a valuable tool in IPM. A few of them (2/9) felt that the problem was that growers tend to treat commercial BCAs as another pesticide. It is very difficult to evaluate the commercial BCAs in this situation because they are always using it as a part of their IPM approach or system approach. It is difficult to generalise across all cropping systems. It is also varies from pest to pest. Commercial BCAs are an important IPM tool but do not have stand-alone use and their importance varies in different cropping systems and with different pests.

In terms of awareness, the release of commercial BCAs increases the growers' awareness about IPM and the biological control agents. One of the researchers reported that:

> "A lot of entomologists do not fundamentally believe in biological control. They have grown up on chemical control and spend their whole life researching chemicals. They have lack of practical experience because [they] spend their time in the laboratories instead of out in the field. So they believed that chemicals are the only solutions because they could not actually see what happens when biological control works."

This quotation indicates that some entomologists do research on chemicals in the laboratory and do not have field experience. As a result they are not aware that biological control actually is working.

5.3.3 Citrus pest management researchers' perceptions of the main barriers which influenced Australian growers

Interviewed researchers expressed views about the main causes for the limited use of commercially available biological control agents by growers.

The size of the market may be influencing the adoption of commercial BCAs. The majority of the researchers (5/9) noted that the numbers of growers are fewer in Australia compared with other countries as in Europe where commercial BCA adoption is higher. A few of them (3/9) noted that the limited numbers of growers actually using commercial BCAs are mostly growing horticultural crops. In addition, broad acre crops are probably the biggest cropping system in Australia, much larger than the greenhouse cropping system. Growers might be interested in looking at naturally occurring biological control agents for broad acre cropping systems. This indicates that the Australian market is limited because of the small number of growers and the large size of broad acre cropping systems where commercial BCAs are less likely to be used for pest control.

A few of the researchers (2/9) pointed out that a very few organic growers were actively using commercial BCAs in Australia. They also said that it seems there is a lack of awareness of the fact that there are commercial BCAs compatible with organic farming available for augmentative releases. Organic growers were not looking for commercial BCAs to introduce in areas where a biological control agent might be absent. Most of the organic growers are non-users of commercial BCAs and perhaps they are not aware of them.

In terms of developing a new commercial BCA, a few of the researchers (3/9) reported that one of the major barriers is bringing a new commercial BCA into the market. Australia has strict biosecurity laws and needs to be very careful about introducing exotic organisms. It is necessary to ensure that the biological control agent is target specific, its host range defined and its impacts on native biodiversity considered. It is also necessary to think about the commercial point of view. It is necessary to look at the whole system; it is very much a case by case basis.

A few of the researchers (3/9) pointed out that the attitude of the growers is another barrier to the adoption of commercial BCAs. One of them reported that:

> "Some of the growers have used pesticides for last 30–40 years and it is very hard to change their attitude. They are getting the results why would they do anything different that has a risk for their crops, their livelihood or their incomes".

They also said that the attitude of some growers is 'chemical or nothing'. Some other growers tend to see insecticides as more like insurance. Growers can easily see the impact of chemical application but they sometimes do not know about commercial BCAs due to the lack of education. A few of the researchers' (2/9) believe that education and extension has a major impact on the growers. They noted that ethnic background (such as Greek, Italian and Lebanese) is another barrier because of cultural and language differences. Perhaps most of the migrant Australian growers whose first language is not English face barriers and this study did not investigate further. A few of the researchers (2/9) also pointed out that risk management is a big issue for growers. If growers know the chemicals are cheap, effective and are getting results then they do not take the more risky decision to use commercial BCAs because they still believe that IPM is a greater risk. The growers' negative attitudes and lack of confidence in commercial BCAs hindered the adoption of commercial BCAs in an IPM program.

One of the main barriers to actually starting an IPM program is that it needs extra time and money spent on monitoring to know what the system is doing. This indicates that IPM requires more time and money than chemicals. Perhaps growers were not aware that once started it became cheaper than chemicals.

Location of the insectary companies may be another barrier. One of the interviewed researchers pointed out that the Australian insectaries are hidden away for just a few selective growers who happened to be thinking about them. Most of the growers outside those areas have nothing in front of them to remind them that there is another option for pest management. Some growers use commercial BCAs because they have suitable climatic conditions but others do not because they have a different climate and pest pressures are different. Thus insectaries were established to supply a local business and do not apply to other regions with different climatic conditions.

Extension services have a large impact on the adoption of commercial BCAs. One of the interviewed researchers pointed out that currently extension is being done quite differently from in the past. Doing more direct research projects and expanding the information from them is considered better than general extension on individual practice. One of the barriers was growers are very much influenced by pest management consultants. The consultants recommend chemicals because if they visit orchards without recommendation then the growers will not bother with them. Thus extension services and pest management consultants play an important role in the adoption of commercial BCAs.

Researchers were asked about the impact of Genetically Modified (GM) technology. The majority of the researchers (7/9) did not comment because they were not expert in GM technology. Only one of them said that GM technology is causing growers not to think about commercial BCAs in an IPM program and the adoption of commercial BCAs was discouraged by GM technology.

5.3.4 Citrus pest management researchers' perceptions of the main driving factors which influenced Australian growers

The main driving factors which influenced growers to switch from conventional (chemical) control to IPM and incorporate commercial BCAs are discussed below:

Most of the researchers (5/9) reported that pesticide resistance is the main reason for growers to switch from chemical pest control to an IPM approach. One of them noted that when insecticides are withdrawn growers are forced to switch to IPM.

A few of the interviewed researchers (3/9) also stated that effectiveness is another driving factor. The commercial BCA needs to provide evidence that it works and it is as effective as the conventional chemical method. This indicates that growers are always looking for cheap and effective practices. If any practices failed to meet these criteria then growers will try to find a new one, which is satisfactory.

Often some forward thinking growers just fundamentally believe that it is better to use less pesticide. A few of the researchers (3/9) pointed out that those growers become more aware of their pests and the beneficial insects. They are aware of the impact of pesticide applications and look for alternatives. In terms of education interviewed researchers (2/9) believed that educated growers tend to adopt IPM more easily than uneducated growers. Perhaps generational shift is another driver believed by a few researchers (2/9). Younger growers more easily adopt IPM. Thus education, generational shift and forward thinking of growers influence the adoption of commercial BCAs.

A few of the researchers (3/9) pointed out that legislation has a big impact on growers switching to IPM programs. They stated that certain regulations are already in place such as the government's rigorous regulations regarding residues. Growers may want to use certain chemicals but the active ingredients are not now registered for use. If their crops are detected with these residues then they will not be able to sell their products.

One of the reasons for IPM use are the purely market demands that may be for the domestic or export market. For a marketing reason growers would like to reduce insecticide use (e.g., European market) or they might like to increase it for other markets (e.g., USA/Asian market) that is looking for blemish free fruit and vegetables. Researchers also stated that growers switch to IPM only for economic reasons. Legislation, market demands, economics and the human health aspect are all factors in the decision to use commercial BCAs. Only a few of the interviewed researchers (2/9) said that there are some growers who genuinely want to use less pesticide possibly for personal health reasons.

5.3.5 Citrus pest management researchers' recommendations for the expansion of this industry

Often collaborative research enhances the expansion of the insectary industry. The majority of the researchers (7/9) were more likely to believe that some collaborative research is certainly possible. Without collaboration there may not be much expansion of the Australian insectary industry. Most of them (5/9) also noted that if the government research organisations work with insectary owners then that will certainly help and not only maintain quality, but also improve quality.

In terms of expertise, nearly half of the researchers (4/9) said that insectary owners do not need to work with researchers because insectary owners are well educated enough to know how to run their own systems.

The insectary companies' size is also important for further expansion of the industry. Most of the interviewed researchers (5/9) noted that the Australian insectary companies are small in size but if they were larger, their production systems will be presumably cheaper and the products more cost effective. This could help the expansion of the industry. One of them said that the size of the company is not important but the way they do the marketing is important. Nearly half of the researchers' (4/9) pointed out that only consumers can help to promote commercial BCAs in the Australian farming system. It will allow the insectary industry to further expand and increase their market share relative to just pesticide sales. This result indicates that both companies' size and marketing can enhance the expansion of the insectary industry.

In terms of legislation, a few of the researchers (3/9) pointed out that the government can legislate to encourage less frequent use of pesticides. Pesticide restrictions may be placed on many uses and this restriction may have influenced the uptake of commercial BCAs. A few of them (2/9) said the government support with the infrastructure of the insectary companies is very important especially with the initial investment.

Education and extension largely influence the adoption of commercial BCAs. A few of the researchers (2/9) said that a representative of an organisation or extension officer needs to be aware of the options. The extension officers who deal with the growers need to have an understanding of the education and awareness of the growers about what is available or what the opportunities are or what IPM is all about. Interviewed researchers also believe that if a researcher or extension person shows that it is a specific technology, and shows the technology is a proven method, that gives a grower more confidence when using the technology. The extension people require education about IPM or commercial BCAs because they are the agents to change growers' attitude and establish growers' confidence in IPM or commercial BCAs.

Interviewed researchers (2/9) said that habitat or ecosystem management is one of the key factors that enhance commercial BCAs effectiveness and influence the adoption of commercial BCAs in IPM program. When a grower puts commercial BCAs in a harsh environment then they will last a relatively short time and then die. It is hard to sustain the population when evident biometrics (food sources, alternative prey, pollen, nectar and habitat for egg laying) does not support them at all. This result places emphasis on habitat management which enhances natural enemies as well as commercial BCAs.

5.4 Discussion

Researchers were unified in their views on the need for augmentative biological control and a viable insectary industry. This result is consistent with other researchers' findings that within the agriculture system the natural biological control agents are either absent or failed to control the pests. This is due to several factors such as climatic and geographic conditions, or lack of host or lack of food or developmental timing and cropping systems (Obrycki et al., 1997; Wissinger, 1997; Sivinski, 2013). Some researchers preferred naturally occurring biological control agents as the first option especially for outdoor crops. Certain ecological limitations such as an environment unfavourable for commercial BCAs, timing of releases and pest-commercial BCA incompatibility may make commercial BCAs less effective (Collier and Steenwyk, 2004; Sigsgaard, 2005). Kelly's citrus thrips, for example, is a serious citrus pest in Southern Australia, New Zealand and several countries in the Mediterranean Region. Perhaps climatic or geographic conditions or their natural enemies are absent in other parts of Australia due to the lack of hosts (Baker et al., 2011). In addition, a high proportion of agricultural insect pests are exotic species because they were introduced into Australia. The Silverleaf whitefly is a serious pest in different crops but no effective natural parasitoids are available in Australia because this pest was introduced in the early 1990s (DeBarro and Coombs, 2009).

It is necessary to discuss IPM adoption here first because commercial BCAs are always used within an IPM program as an IPM tool.

Researchers expressed a range of views about the definition or meaning of IPM and this meaning has a large influence on the adoption of IPM. The adoption of IPM by growers is also influenced by several other factors such as the cropping system, pests, natural enemies, and geographic location of the system. In one region, such as in Italy, the olive industry has been considered as suitable for IPM. In other production areas of the world such as in Australia, with low adoption of IPM, it was related to factors such as the diversity of olive agroecosystems (New, 2002). Similarly, in some cropping systems or geographic locations or for some pests, the use of pesticides is inevitable because there are no effective alternatives such as IPM (Furlong et al., 2008; Zalucki et al., 2009). All of these factors need to be considered when assessing the adoption of IPM and commercial BCAs.

Interviewed researchers also said that often market destination influences growers to use or not to use pesticides and to adopt IPM. Recently the citrus industry became export oriented and different markets require different quality especially in fresh products. Other researchers noted that often fresh market fruit is not allowed to have the same level of damage, especially cosmetic damage, as fruit for processing (Urquhart, 1999; Kaine and Bewsell, 2008). As a consequence, growers do not have a choice other than the use of pesticides. Conversely, many export markets ordered growers to change their chemical based pest control practices to an IPM program. This is because of the requirements of certain levels of pesticide residue limits in their fresh produce. Therefore, the adoption of IPM may be influenced positively or negatively by the export market.

The use of selective insecticides in IPM is another important factor that influences the uptake of commercial BCAs in IPM programs. Selective insecticides with commercial BCAs work well together, although sometimes have a negative effect on non-target species. This result is consistent with that of other researchers who found that selective insecticides sometimes kill or change the behaviour or effectiveness of these non-target species of biological control agents (Horne et al., 2008; Gentz et al., 2010). Perhaps selective insecticides make commercial BCAs' effectiveness questionable. Many researchers reported that the combined use of selective insecticides and commercial BCAs to control agricultural pests have created complicated issues in IPM because selective insecticides may have toxic effects on other biological control agents (Holt and Hochberg, 1997; Dent, 2000; Devine and Furlong, 2007; Gentz et al., 2010). This may be one of the factors that deterred growers from using commercial BCAs in an IPM program.

Interviewed researchers said that insecticide resistance is the main driving factor that influences growers to switch from chemical pest control to an IPM program and adopt the commercial BCAs. This result is consistent with other results that identified insecticide resistance as one of the main driving factors for the adoption of commercial BCAs and which are recognised around the world (van Lenteren and Bueno, 2003; Pilkington et al., 2010; Cock et al., 2010). In Australia, one of the major pests, red scale (*A. aurantii*) in citrus crops developed organophosphate resistance in the 1990s (Collins et al., 1994; New, 2002). Afterwards, Australia developed a successful IPM program for the citrus crops and incorporates commercial BCAs (New, 2002).

Effectiveness of the commercial BCAs is an important factor which may drive the Australian insectary industry expansion. Other studies have found it necessary to prove that commercial BCAs effectively control pests (van Lenteren and Bueno, 2003; Pilkington et al., 2010; van Lenteren, 2012; Rebek et al., 2013). Some researchers doubted commercial BCAs' effectiveness compared with pesticides (Collier and Steenwyk, 2004). This inconsistency can be explained by one of the interviewed researcher's comments who said that many entomologists did not believe that biological control actually works because they did not have practical field based experience.

The industry needs to produce cost effective products for its expansion. Many studies found that commercial BCAs carry a higher cost than chemical pesticides in either direct costs or indirectly. This result is consistent with other researchers' findings that the labour of monitoring and releasing, or using commercial BCAs with pesticides, is more expensive than pesticide application alone (Olsen et al., 2003; Collier and Steenwyk, 2004; Moser et al., 2008). Often selective insecticides are more expensive than broad-spectrum insecticides and using commercial BCAs with selective insecticides makes it expensive. Other researchers argued that the cost of the commercial BCAs were significantly less important factors in terms of adoption (Wawrzynski et al., 2001). Perhaps cost is less important to growers when only one option is available that is expensive but very effective.

Growers' attitude is an important factor in the adoption of commercial BCAs. This result is consistent with other researchers' findings in Australia and overseas that adoption of new technology was hindered by the growers' perceptions or attitudes of increased risk because any change is stressful. This has significant influence on the growers' decision making process (Feder et al., 1985; Pannell et al., 2006; Horne et al., 2008). This consistency indicates that growers' attitudes are similar around the world. Many researchers pointed out that growers could overcome risk if growers can trust commercial BCAs. They could be willing to experiment and adopt commercial BCAs into their IPM program (Trumble, 1998; Moser et al., 2008; Horne et al., 2008).

This result shows that the cropping system may be one of the main barriers for the expansion of this industry. In Australia, the broad acre cropping system is the biggest cropping system compared with the much smaller greenhouse cropping system. Previous studies revealed that IPM is not adopted or little-adopted by broad acre cropping growers for pest management in Australia (Williams and Il'ichev, 2003; Horne et al., 2008). In many broad acre cropping systems IPM is not well developed. Perhaps using commercial BCAs and IPM in broad acre cropping is not very cost effective because of other expenses such as monitoring and releasing of commercial BCAs. This might be one of the economic limitations.

Organic growers are apparently not buyers of commercial BCAs in Australia. Many researchers, and the national and international guidelines, recommend the use of commercial BCAs for pest management in organic farms (Horne, 2007; Neeson, 2007; Zehnder et al., 2007; Madge, 2009). However, organic growers are described as 'non-users'. Other studies found that organic growers use insecticides that are registered for the organic system to control pests or use conservation biological control to manage the cropping system (Furlong et al., 2004; Macfadyen et al., 2009). Organic growers may accept certain levels of crop damage because growers get higher pay for organic produce than for normal crops (Monk, 2012). This result indicates that perhaps organic growers were not aware that commercial BCA is another option for their pest control.

To develop a new commercial BCA is one of the major barriers in Australia. The Australian insectary industry does not have the capacity to conduct this type of applied research. This industry is dependent on the public agencies and the universities for research in Australia. Survey of the North American insectary industry revealed that it was difficult to find a researcher who is willing to do the research to develop a new commercial BCA. Most of the researchers prefer classical biological control research because if successful then there is no need for further investment (Warner and Getz, 2008). This type of applied research has been reduced in North America due to a lack of funding (Warner, 2007). The Australian researchers perhaps face similar problems. This study revealed that the current rules and regulations make it harder to bring a new commercial BCA into the market. Many researchers perceived that restriction of international movement of live arthropods created barriers to augmentative biological control (Warner and Getz, 2008; Cock et al., 2010; van Lenteren, 2012). Despite this restriction one of the exotic species, a parasitoid, *Eretmocerus hayati*, shipped from Texas to Australia and released in the late 2004 for host range testing and evaluation, has been developed as a commercial biological control agent (Goolsby et al., 2005; DeBarro and Coombs, 2009). Currently this parasitoid is available in the Australian commercial BCAs market to control Silverleaf whitefly (an introduced pest in Australia) (Bugs for Bugs, 2015). Interviewed researchers pointed out that in Australia, most of the pests are introduced and the endemic natural biological control agents could not control them. It is necessary to introduce some exotic species of commercial BCAs. Insectary owners need collaboration to develop a commercial BCA. They need to follow the multi-target approach to develop a commercial BCA that controls a key pest of multiple crops or controls multiple key pests in a particular crop or different crops.

Interviewed researchers recommend the same recommendations as other studies do. Growers are largely influenced by consultants. In Australia, extension provides information, distributed collectively, rather than one-on-one general extension services, as in the past and which was perhaps more useful. Some researchers noted that extension officers need to show how the commercial BCAs can be integrated with other crop management options within a farming system (Williamson, 1998; Wawrzynski et al., 2001; Horne et al., 2008; Kaine and Bewsell, 2008; Warner and Getz, 2008). Several studies have revealed that the failure to adopt IPM largely depended on the lack of growers' education and extension services (Malone et al., 2004; Kaine and Bewsell, 2008). Interviewed researchers recommended that extension officers needed training about IPM and that training programs should show how they can change growers' attitudes and practices.

In terms of legislation as a driving factor, interviewed researchers recommended that pesticide restriction may enhance the uptake of commercial BCAs. Many countries such as those in the European Commission actively encourage the uptake of low input or pesticide-free agriculture. The United Kingdom's "Pesticides Safety Directorate" reduced the registration fees in 2006 for biopesticides to promote the uptake of biological control by growers (Pilkington et al., 2010; van Lenteren, 2012). Many countries have withdrawn hazardous pesticides or levy pesticide taxes to promote commercial BCAs (Cannell, 2007; van Lenteren, 2012). Interviewed researchers recommended that the industry needs financial support from the Australian government. Other studies recommended that it was necessary to create small business loan programs to assist this industry not only for infrastructure but for business expansion or quality improvement (Warner and Getz, 2008). In many countries such as Brazil, China, Colombia, Mexico and Peru commercial insectaries and government funded insectaries are operated (van Lenteren and Bueno, 2003). Perhaps the Australasian Biological Control Association Inc. could join with other related associations and form a lobby group to try to convince the government to act.

Consumers' awareness is very important because this driver can change the entire supply chain. Interviewed researchers identified supermarket roles, IPM certifications, and consumers' awareness. This awareness is not only important in the citrus industry but also in other industries as well. Consumers can create market pull that changes the growers' thinking about the use of pesticides (Pilkington et al., 2010; van Lenteren, 2012). In Europe, to increase the public awareness the non-government organisations (NGOs) educate the public about pesticide contamination and to demand higher food standards

(Cannell, 2007). In addition, in Canada survey results revealed that consumers preferred foods produced using biological control than those using synthetic pesticides (Cannell, 2007; McNeil et al., 2010). In this study, researchers' complained that in Australia there is no such type of encouragement and supermarkets and industries were reluctant to promote IPM.

In terms of the ways of pest management, this result is consistent with many researchers' recommendations such as conservation biological control and sustainable agro-ecosystems which withstand pest and disease problems (Lewis et al., 1997; van Lenteren and Bueno, 2003). In addition, it is important to focus on the whole problem not only a small piece of it. Researchers often focus on a single pest where other pests were present. Often they focus on research rather than implementation. As a result chemical based control still works and IPM is still represented as a partial solution to pest management (Olsen et al., 2003; Cumming and Spiesman, 2006; Horne et al., 2008).

5.5 Conclusions

This study shows that commercial BCAs are a valuable tool in IPM. Insecticide resistance is working as a main driving force for growers to switch from conventional pest control to IPM programs that incorporated commercial BCAs. Several other factors make notable influences on growers as well. The Australian insectary industry as a small scale operator faces major challenges to bring a new commercial BCA into the market. Several areas needed further research such as selective insecticide use in IPM and commercial BCA use in organic cropping systems. Interviewed researchers made several recommendations. It is necessary for these recommendations to be considered and to create more favourable conditions for commercial BCAs and the Australia insectary industry expansion.

Chapter 6: Citrus growers' interviews and surveys

This chapter focuses on citrus growers to understand the Australian growers' attitudes towards the use of commercial biological control agents (commercial BCAs) or augmentative biological control which is one of the important tools in Integrated Pest Management (IPM). Citrus was the first crop in Australia on which commercial BCAs were used and citrus growers remain key stakeholders in the Australian commercial insectary industry.

This chapter addresses the specific Objective 3 (Chapter 1 and Chapter 3, Figure 3.2):

> To examine the viability of the commercial insectary industry in Australia with particular reference to its use in the citrus industry and identify citrus growers' attitudes towards the use of commercial BCAs.

The experiences and views of the citrus growers about their adoption of commercial BCAs were considered. The chapter presents different factors which influence the adoption process.

To address this, the author first interviewed a small sample of citrus growers to understand the range of views. From this a questionnaire was developed for a national survey. This survey was aimed at generating quantifiable reliable data to understand the perspectives of the larger population of the citrus growers in Australia. Despite significant efforts to recruit respondents, there was a low response. Only 72 respondents participated in the national survey. Therefore in most instances data were analysed qualitatively.

6.1 Introduction

Previous studies have shown that the adoption of agricultural technology is a decision-making process which depends on how growers perceive technology (Makokha et al., 1999; Chi and Yamada, 2002; Akudugu et al., 2012). This in turn depends on economic, social, institutional and environmental factors that influence the process of adoption (Chaves and Riley, 2001; Moser et al., 2008). Key factors include the relative advantage of a new practice over existing practices. Characteristics of the technology itself affects how easily the landowner can learn about its performance and optimal management (Pannell et al., 2006). Other studies focus on growers' demographics, their enterprises and how growers' attitudes influence how they respond to new technology (Kaine and Bewsell, 2008; Moser et al., 2008; Sadati et al., 2010). In Europe, for example, growers' confidence in commercial BCAs was significantly enhanced because they were more aware of the positive aspects than the negative aspects (Moser et al., 2008). Often government support or rules influence the adoption of technology. Many European countries support growers to implement commercial BCAs in an IPM program. The Israeli government partially subsidised the packaging of commercial BCAs and offered free technical support at the beginning of the program (Moser et al., 2008). In a Californian citrus growers' survey undertaken in 2010, the results showed that growers with larger citrus acreage and more education were more likely to use commercial BCAs (Grogan and Goodhue, 2012). These insights were incorporated into the design of the interview format and the survey questionnaire.

6.2 Methods

This section describes the interviews of citrus growers and the survey of the larger community of growers. In this study, the term 'users' means those growers who purchase and use commercially produced biological control agents (arthropods or nematodes) to control insect and/or mite pests in their crops. The term 'non-users' means growers who do not currently use commercial BCAs. These terms will be used in both interviews and the survey.

6.2.1 Citrus grower interviews

Nine commercial citrus growers were interviewed. They were recruited through the insectary owners, Citrus Australia Ltd. and consultants. The method of selection involved the identification of 14 growers who were described as adults (over 18 years of age and growing citrus crop) and from different states in Australia. Each was contacted briefly and then a list of ten citrus growers was compiled. Then the growers were interviewed until no new information or views were emerging from subsequent interviews which indicated that data saturation had been reached. This resulted in interviews from nine commercial citrus growers (including two citrus farm managers) conducted by the author in 2011.

Ethics approval was granted by the University of Sydney Human Research Ethics Committee before the interviews commenced (Approval protocol No: 13278, 14th December 2010). Before conducting the interviews each respondent received a Participant Information Statement (PIS), consent form and cover letter (Appendix 3). Maintaining anonymity was achieved through de-identification and data aggregation.

Participation was entirely voluntary. Motivation to participate was stimulated by emphasising the relevance of the study to the future pest management system.

Semi-structured interviews were conducted, four in person (face-to-face) and five by telephone. The same interview protocol was followed as described in Chapters 4 and 5. An interview pro-forma was developed based on different topics or areas such as general, economic, technological and institutional information, growers' perceptions and their characteristics (demographics) (Appendix 9). Quantitative data were collected on general information, the economic situation of the farm and the growers' characteristics. The remaining data were qualitative.

The interviews had an average length of 52 minutes and were audio-recorded then transcribed using Express Scribe software (Express Scribe v 5.55© NCH). Before analysis, the transcribed text of the appropriate interview was sent to each interviewed grower for approval.

Analysis of Citrus growers' interviews

Theme analysis was conducted and followed the same procedure as described in Chapters 4 and 5 interviews. Text data were coded using NVivo 10.0 text analysis software using a structural coding approach (Namey et al., 2008). Each topic was coded as: GINFO for General information, EF for Economic factors, TC for Technology characteristics, GP for Growers' perceptions, IF for Institutional factors and PC for Participants' characteristics (demographics). Within a topic, each question was given a code name which contained a prefix for the topic and an identifier for the question such as: GINFO_farm ownership, EF_farm size, TC_familiarity with BCA, or GP_BCA features. The full lists of these codes are in Table 6.1.

Table 6. 1: Interview code (node in NVivo) descriptions. There were six topic codes and each topic code has a group of question codes.

Code	Code descriptions
1. Code: GINFO	**General information**
GINFO_farm ownership	Citrus growers' farm ownership.
GINFO_farm management experience	Citrus growers' farm management experience.
GINFO_heard about BC	Has citrus grower heard about biological control (BC)?
GINFO_approach uses for pest control	Which approach (conventional or IPM) used for pest control?
GINFO_currently use BCA	Does grower currently use commercial BCA?
2. Code: EF	**Economic factors**
EF_farm size	Farm size.
EF_pest management expenses	Approximate pest management expenses.
EF_source of income	Is this farm the main source of income?
EF_pesticide related sickness	Has grower become sick as a result of pesticide use?
EF_employees	Full-time and part-time employees working on the farm.
3. Code: TC	**Technology characteristics**
TC_familiarity with BCA	Growers' familiarity with commercial BCA.
TC_commonly used BCA	Most commonly used commercial BCA.
TC_BCA used for pests	Commercial BCA used for which pests?
TC_training	Does grower need training to use commercial BCA?
TC_main problems	Encounter any problems when using commercial BCA?
TC_difficulties to use BCA and pesticides together	Encounter any difficulties when using commercial BCA and pesticides together?
TC_time lapses between BCA and pesticide application	Time lapses between pesticide application and use of commercial BCA.
TC_successful BC experience	Successful biological control (BC) experiences.
4. Code: GP	**Growers' perceptions**
GP_BCA features	Main features of biological control agents (BCAs) that distinguish them from conventional tools.
GP_BCA efficacy	Growers trust in the efficacy of commercial BCAs.
GP_reasons for BCA use or not	Reasons for use of commercial BCAs.
GP_profitable or risky decision	Using commercial BCA is profitable or a risky decision?
Gp_BCA cost more	Do commercial BCAs cost more than pesticides?
5. Code: IF	**Institutional factors**
IF_sources of information	Sources of information on the topic of pest management.
IF_help from government	Does grower get any help from government?
IF_convince to use BCA or pesticide	Which factors convinced growers to use commercial BCAs or pesticides?
6. Code: PC	**Participants' characteristics (demographics)**
PC_age groups	Participants' age group.
PC_education	Participant education level.
PC_farm location	Location of farm.
PC_gender	Participant gender.
PC_family members	Participant family members working on the farm.

This coding was used to generate NVivo queries which were used to interrogate the data and formed the basis for further analysis and interpretation. The coded data were then categorised or classified according to the emerging themes where the meaning of responses was consistent and unambiguous. Through this process, all examples of each theme were pulled together so that the results from interviews could be interpreted for those themes.

6.2.2 Citrus grower surveys

Citrus Australia Ltd. was consulted to get support for a national survey of growers. Before conducting the survey ethics approval was granted by the University of Sydney Human Research Ethics Committee (Approval Protocol No: 14675, 19 April 2012). Motivation to participate was stimulated by emphasising the relevance of the study to the future pest management system. In the Participant Information Statement it was clearly stated that submitting a completed questionnaire is an indication of consent to participate in the study.

Survey design

After conducting the nine citrus grower interviews the survey (questionnaire) was developed. The following aspects were considered as suggested by other researchers (Escalada and Heong, 1997):

1. The precision of the questionnaire phrasing,
2. The clarity of the questionnaire instructions,
3. The questions were in a coherent and logical sequence,
4. The adequacy of the response categories.

The final questionnaire was pilot-tested with the nine interviewed citrus growers who were asked to comment on whether any of the questions needed clarification. The survey consisted of 34 questions including YES/NO, multiple-choice, open-ended and Likert-type scale questions and completing tables of information. All questions were for commercial BCA 'users' and 'non-users' except Question 21, Question 28, Question 29, Question 31 and Question 32 for 'users' only and Question 27 and Question 30 for 'non-users' only. The survey consisted of six topics or areas which were considered potential determinants for the adoption of a commercial BCA for pest management. The topics were:

Section I Participants' characteristics (demographics),
Section II Economic factors,
Section III General information about citrus farm practices,
Section IV Growers' perceptions,
Section V Technology characteristics,
Section VI Institutional factors.

Each topic consisted of a group of questions. The rationale for including each variable in this study was explained in Chapter 3 (Research Methodology). A copy of the questionnaire is in the Appendix 10.

Participants' characteristics (demographics)

The questionnaire Section I (Appendix 10) is focused on growers' demographic information. Information was collected on the grower's role, farm managing experience, level of education, age group, gender, number of employees and farm location. This section consisted of seven questions (Questions 1–7) (all of which were considered as variables) for both users and non-users.

Economic factors

The questionnaire Section II (Appendix 10), consisted of four questions (Questions 8–11). Farm size, crop values, pest management expenses and crop losses were all considered as variables. These questions were for both users and non-users.

General information about citrus farm practices

The questionnaire about the citrus farm Section III (Appendix 10), focused on the farm and farm practices and consisted of 11 questions (Questions 12–22). This includes crop varieties, market destination, intercropping, cover cropping (binary YES/NO), IPM tools, decision maker, economic thresholds and their measurement, using pesticides, using commercial BCAs and monitoring biological control agents. In this section all questions were included as variables. Question 21 was designed only for 'users' and the remaining questions were designed for both groups.

Growers' perceptions

The questionnaire Section IV (Appendix 10), is focused on eight questions (Question 23–30). Each question consisted of several statements (items) with a five-point Likert-type scaled question (Strongly Disagree-Strongly Agree). These questions were: requirements for IPM practices, pesticide use, effects of insecticide on biological control agents, insecticide application strategy, why citrus growers do not use commercial BCAs, what influences the decision making process, why citrus growers use commercial BCAs and non-user attitudes towards commercial BCAs. In this topic, Questions 27 and 30 were designed for non-users and Questions 28 and 29 were only for users. The remaining questions (Questions 23–26) were for both groups. In this section, some of the statements (items) were similar in different questions which interrogated the data reliability. In Question 27 some statements such as: not effective, too expensive and not profitable were used for non-users. The same statements were posed in a positive way in Question 29 for users. Questions 28 and 29 used some common statements such as: 'concerned about health risks' or 'safer for health' and 'concerned for the environment' or 'safer for the environment'.

Technology characteristics

The questionnaire Section V (Appendix 10), is focused on the complexity of using commercial BCAs, using a five point Likert-type scaled (Strongly Disagree-Strongly Agree) question (Question 31) and the frequency of pesticide application in combination with commercial BCA using a binary (YES/NO) question (Question 32). These two questions were designed for users only. Question 31 used some common statements from Question 27 such as ‘labour-intensive’, ‘need a consultant’ and ‘training’.

Institutional factors

The questionnaire Section VI (Appendix 10), is focused on the sources of information using a binary (YES/NO) question (Question 33). It also asked about support from the government or other organisations using a five point Likert-type scaled (Strongly Disagree-Strongly Agree) question (Question 34). The two questions were designed for both groups.

The online survey was created using Survey Monkey software. Multiple responses from the same computer were avoided by selecting appropriate options.

Selection of Participants

The survey web link, Participant Information Statement (PIS) and an invitation cover letter was sent to Citrus Australia Ltd. Then it was forwarded to their growers (1867 in total) on 22 June 2012 through their national email network. On 3 August 2012, a survey reminder letter was circulated through the email network of Citrus Australia Ltd. A survey invitation letter was published in the Australian citrus magazine “Australian Citrus News” (Volume 89, June/July 2012, Appendix 4). Then an invitation cover letter (2300 copies) of this survey was sent to the mail house of the Australian citrus magazine

"Australian Citrus News" (Appendix 5). They sent these copies of the handout to the citrus growers with this magazine (Volume 90, August/September 2012). This ensured that magazine subscribers who were not part of the e-mail network were alerted to the survey and increased the potential population size by almost 500 people compared with e-mail communication alone. To increase survey responses, the surveys (cover letter, questionnaires, PIS and self-addressed envelope) were also sent to the insectary companies, packaging sheds and some citrus growers who were willing to circulate the surveys. Clear instruction was given to the participants to ignore the survey if growers had already responded.

Participants were also recruited through Citrus Australia's three Regional Forums and Variety Days' workshops in the Riverland (Waikerie, 18 March 2013) Sunraysia (Dareton, 20 March 2013) and the Riverina (Leeton, 22 March 2013). A list of contact details for 142 citrus growers was prepared based on searches of Google and the Yellow Pages (Australian Postal Services). Surveys were mailed to the citrus growers and then followed-up by telephone calls. Only a few numbers of growers were available for contact. Some of them had changed their telephone numbers. Others do not produce citrus anymore. Online data collection was closed in June 2013.

Afterwards, all hard copy survey responses were collected from workshops and other sources and were entered manually into the Survey Monkey software. All of these hard copies as well as on-line surveys totaled 72 responses for analysis.

Analysis of citrus grower survey

The survey consisted of six topics or areas (Sections I–VI) as shown in Appendix 10. Each topic contained a group of questions. These topics were coded as: A for Section I, B for Section II, C for Section III, D for Section IV, E for Section V and F for Section VI for the analysis in SPSS software (Table 6.2). The coded questionnaire was presented in Appendix 10. Each question was coded first by topic (A, B, C etc.) then question number such as A1, A2, B8, and F34. Some questions have several statements or item variables. These were coded by using the question code and then numeric code for that variable such as A1 1, B8 1, and F34 1. The codebook or questionnaire code description, number of responses and the analysis that was performed are in Table 6.2 under the headings: Participants' characteristics (demographics), Economic factors, General information about citrus farm practices, Growers' perceptions, Technology characteristics and Institutional factors.

Table 6.2: The codebook or questionnaire code descriptions, number of responses (n) and the analyses that were performed.

Detailed questionnaire codes are in Appendix 10.

Question codes	Variable types	No. of responses (n)	Description of variables	Coding instructions	Analysis performed
A			**Participants' characteristics**		
A1	Nominal	72	Growers' role in orchards	1 = Owner, 2 = Manager, 3 = Others	Cross tabulation
A2	Scale	71	Farm managing experience	In years	Compared means
A3	Ordinal	72	Levels of education	Each level was given a numeric code	Cross tabulation
A4	Ordinal	72	Age group of grower	Each group was given a numeric code	Cross tabulation
A5	Nominal	72	Gender of grower	1 = Male, 2 = Female	Cross tabulation
A6	Ordinal	70	Number of employees	Each range was given a numeric code	Cross tabulation
A7	Nominal	72	Farm location	Each state was given a numeric code	Cross tabulation
B			**Economic factors**		
B8	Ordinal	72	Size of the farm	Each range was given a numeric code	Cross tabulation
B9	Ordinal	70	Crop values per year	Each range was given a numeric code	Cross tabulation
B10	Scale	61	Pest management cost per year	In dollars (AUD$)	Compared means
B11	Ordinal	72	Level of crop losses and acceptable to the grower	Each range was given a numeric code	Cross tabulation
C			**General information about citrus farm practices**		
C12	Ordinal	72	Percentage of crop types	Each range was given a numeric code	Cross tabulation
C13	Ordinal	72	Market destination of the crops	Each range was given a numeric code	Cross tabulation
C14	Nominal (Binary)	71	Intercrop citrus with other crops	1 = NO, 2 = YES	Cross tabulation
C15	Nominal (Binary)	72	Cover crops	1 = NO, 2 = YES	Cross tabulation
C16	Nominal (Multiple choice)	58	Type of IPM tools grower used	Each variable was given a numeric code, 1 = NO, and 2 = YES	Cross tabulation
C17	Nominal	71	Decision maker of pest management	1 = Owner, 2 = Manager, 3 = Consultant, 4 = Owner and manager, 5 = Owner and consultant, 6 = Manager and consultant, 7 = Others	Cross tabulation
C18	Nominal	70	Follow economic thresholds	1 = NO, 2 = YES, 3 = Don't know	Cross tabulation
C19	Nominal	49	Measure economic thresholds	1 = monitoring, 2 = visual check, 3 = fruit damage count, 4 = fruit doctor or consultants and 5 = others	Text analysis (used Nvivo), then Cross tabulation

Question codes	Variable types	No. of responses (n)	Description of variables	Coding instructions	Analysis performed
C20	Nominal	58	Pesticide use for pest and how often	Each variable and each item was given numeric code	Cross tabulation
C21	Nominal	40	Commercial BCAs use for pest and how often	Each variable and each item was given numeric code	Frequency distribution
C22	Ordinal	46	Monitoring biological control agents	1 = Never, 2, 3, 4, 5 = Always	Cross tabulation
D			**Growers' perceptions**		
D23	Ordinal	66	Requirements for practicing IPM	1 = Strongly Disagree, 2, 3, 4, 5 = Strongly Agree	Cross tabulation
D24	Ordinal	52	Why use pesticides	1= Strongly Disagree, 2, 3, 4, 5 = Strongly Agree	Cross tabulation
D25	Ordinal	65	Effect of insecticides on biological control agents	1= Strongly Disagree, 2, 3, 4, 5 = Strongly Agree	Cross tabulation
D26	Ordinal	66	Insecticide application strategy	1 = Strongly Disagree, 2, 3, 4, 5 = Strongly Agree	Cross tabulation
D27	Ordinal	31	Why not use commercial BCAs	1 = Strongly Disagree, 2, 3, 4, 5 = Strongly Agree	Frequency distribution
D28	Ordinal	54	What influenced decision making	1 = Strongly Disagree, 2, 3, 4, 5 = Strongly Agree	Frequency distribution
D29	Ordinal	44	Reasons for commercial BCAs use	1 = Strongly Disagree, 2, 3, 4, 5 = Strongly Agree	Frequency distribution
D30	Ordinal	52	Non-users attitude towards commercial BCAs	1 = Strongly Disagree, 2, 3, 4, 5 = Strongly Agree	Frequency distribution
E			**Technology characteristics**		
E31	Ordinal	51	Complexity of commercial BCAs used	1 = Strongly Disagree, 2, 3, 4, 5 = Strongly Agree	Frequency distribution
E32	Ordinal (Binary)	52	Pesticide application frequency with commercial BCAs	1= NO, 2 = YES	Frequency distribution
F			**Institutional factors**		
F33	Nominal (Binary)	65	Sources of information	1 = NO, 2 = YES	Cross tabulation
F34	Ordinal	65	Organisations help	1 = Strongly Disagree, 2, 3, 4, 5 = Strongly Agree	Cross tabulation

Each question was analysed separately using SPSS (IBM® SPSS® statistics, version 22.0) software.

The classification of growers as 'users' and 'non-users' of commercial BCAs was an important and problematic component of the analysis. The questionnaire was designed to separate them cleanly but analysis revealed anomalies that needed to be addressed to ensure reliable classification of users and non-users. The following paragraphs describe how this reliability was achieved.

Responses were divided into two groups: users and non-users. They were based on the answers to several questions, namely B10, C16, C21, D27, D28, D29, E31, E32, F33 and F34. Among them, Questions C21, D28, D29, E31 and E32 were specially designed for those users who use commercial BCAs. The group of non-users do not use commercially produced BCAs. In this analysis, this categorical variable or nominal variable (in SPSS software) was coded as users = 1 and non-users = 2.

The non-user group also included a few growers whose response to question D27 was that 'they have tried commercial BCA before but it was not effective'. Responses to other questions also indicated that they had used commercial BCAs in the past but did not use them now. In Question B10, a few growers gave expenses for commercial BCAs which were actually compost tea or other microbial biological control agents, not commercial BCAs. These growers were also classified as non-users. Question C16 was for growers who use IPM. Perhaps some growers did not use augmentative biological control (releases of biological control agents) or did not understand the term augmentative biological control. They ticked "YES" but other questions indicated that they do not use commercial BCAs. Growers were considered as non-users if they did not give commercial BCA expenses in Question B10 for pest management and the rest of the questions indicated that they did not use commercial BCAs.

Some participant growers ticked "NO" in response to augmentative biological control in Question C16 but in question B10 they gave commercial BCA expenses for pest management. In Question C21 they wrote that currently they use commercial BCAs. In the open-ended text boxes they wrote that they release insects. They also left out Question D27 and/or the rest of the Questions (D28, D29, E31, E32, F33 and F34), showing that they use commercial BCAs. They were classified as users.

All the open ended comments were checked for relevancy then reported in the results section as text. When participants left out whole questions then these were automatically considered as missing data and were coded as number 99. When participants left out some of the question statements or items these were also considered as missing data and coded as number 99. Cross tabulation, frequency distribution and compared mean analysis were used where appropriate to the type of data collected from each question. Cross tabulation was used to report the differences between the users and non-users. Cross tabulation was the basic tool used to explore the relationship between the two groups of growers. Frequency distribution was used in questions C21, D28, D29, E31 and F32 to report users only and in questions D27 and D30 to report non-users only. Compared mean was used in scale data to report Questions A2 and B10.

6.3 Results

The results from the citrus growers' interviews and national survey of the Australian citrus growers are combined to avoid repetition. Only the most relevant results are given in the following section. The remaining summary statistics that are referenced in the text are provided in Appendix 11. This is to make the central information clearer by avoiding the presentation of too much detail (Trochim, 2000).

Despite a concerted effort to recruit more respondents, only 72 participants completed the surveys which represented about 4% of the total population (approximately n = 2000) of Australian citrus growers. In order to assess whether this small sample was representative of the national citrus growers' population, the sample data were compared to sparse national data available on the demographics of citrus growers and the financial and physical characteristics of citrus orchards. Data from this sample were similar to the national citrus grower population data in terms of age, gender, education, farm location, farm size and crop varieties. These results are broadly consistent with those found in other studies (Kaine and Bewsell, 2008; Sette et al., 2011).

The responses to Questions B10, C16, C21, D27, D28, D29, E31, E32, F33 and F34 identified users (35) and non-users (37) in a total of 72 participants. Among the non-users, a subset (10) was identified who had used commercial BCAs in the past. In this study, they were considered as non-users because of their current pest management practices. They answered questions designed for both the users and the non-users. Some of the surveyed citrus growers did not answer every question because seven of them were for users or non-users only. The responses for individual questions ranged from 72 to 31 (Table 6.2).

This study systematically acquired data which explore citrus growers' perceptions to the use of commercial BCAs in their orchards for pest management. This information will be valuable for the insectary and citrus industry as well as other horticultural industries in Australia. In both interviews and survey there were some differences found between the users and non-users. Qualitative analysis was performed with the interview data. In view of the low response rate in the survey there were few statistically significant differences found in quantitative analysis (Questions B8 and B9). It was useful and appropriate to use these survey results to give qualitative inferences and inform recommendations. The resulting interpretation followed the "The National Foundation for Educational Research in England and Wales" guidelines (www.nfer.ac.uk/schools/developing-young-researchers/how-to-present-your-results.cfm). In this section, abbreviations were used to interpret the result of Likert-type questions such as SD for Strongly Disagree, D for Disagree, U for Undecided, A for Agree and SA for Strongly Agree.

This section does not follow the order of questions. The results from interviews and survey data were triangulated. This section presents triangulated results under six key themes which were identified from the citrus growers' interviews. These themes were considered as potential determinants for the adoption of commercial BCAs for pest management. The six key themes became the subheadings (6.3.1, 6.3.2, 6.3.3 etc.) for the results of the interviews and survey (Table 6.3).

Table 6.3: Themes identified from analysis of interviews with citrus growers.

Themes	Name of the Theme
6.3.1	Characteristics of growers (demographics).
6.3.2	Farm practices relevant to pest management.
6.3.3	Economic characteristics/factors.
6.3.4	Institutional factors.
6.3.5	Citrus growers' perceptions of the main barriers towards the use of commercial BCAs.
6.3.6	Citrus growers' perceptions of the main driving factors towards the use of commercial BCAs.

Users have bigger citrus orchards (more than 40 hectares of land under citrus crop), have more employees (11–20 or more than 20 full-time employees) and achieve more crop values per year (more than AUD$800,000). Non-users have smaller citrus orchards (less than 40 hectares of land under citrus crop), few employees (less than one to five employees full-time) and achieve less crop values per year (AUD$100,000–200,000 per year). Repetition of these economic characteristics of users and non-users might also be found in the following sections (results interpretation) as well as the discussion because this study identified these economic factors as significantly different between users and non-users.

6.3.1 Characteristics of growers (demographics)

This section presents results from the citrus growers' interviews and survey. The interview results from the nine citrus growers are shown in Table 6.4. The citrus growers' characteristics include: growers' role in the citrus orchards, citrus farm managing experiences, level of education, age, gender and location of the farm.

The majority of the interviewed citrus growers (7/9) owned their farm and possessed university degrees (5/9) (Table 6.4). All of them were male and most of them (7/9) belonged to the 40–60+ age group. They were located in four different states with the majority in South Australia (4/9) and Queensland (3/9). The average length of time managing citrus farms was 15 years.

Table 6.4: The interviewed growers' characteristics (demographics).

Farm ownership	Owner 7	Manager 2			
Levels of education	University 5	College 2	Secondary 2		
Age group	20–29 1	30–39 1	40–49 3	50–59 2	60 + 2
Gender	Male 9	Female 0			
Farm location	NSW 1	QLD 3	SA 4	VIC 1	
Farm managing experience	< 10 years 3	10–20 years 3	> 20 years 3		

The survey results of Questions A1, A3, A4, A5, and A7 are shown in Table 6.5.

Most of the results in Table 6.5 showed that the distribution of users (35) and non-users (37) are similar. The results of the survey showed that the majority of citrus growers (n = 72) were male (66) (A5), and owned their farm (52) (A1). They were evenly distributed among the age groups but the majority were between 50–59 years in two age brackets (12+14 = 26) (A4) (Table 6.5). This result is consistent with the proportion of male and female farmers (72% and 28%) nationally and the national farmers' median age of 53 years (ABS, 2011).

All 72 survey participants had secondary education and the majority (users 22 and non-users 24) had some form of tertiary education (A3) (Table 6.5). The education distribution of citrus growers in this study is broadly consistent with studies of other horticultural growers in Australia (ABS, 2003; Kaine and Bewsell, 2008).

Non-users were somewhat more likely to own and operate their farm. Users (9) employed more managers than non-users (6). Slightly fewer users (7) possessed TAFE/Technical/ Agricultural college qualification than non-users (10). Survey respondents were from New South Wales (35) followed by South Australia (18), Queensland (8), Western Australia (6) and Victoria (5). No responses were received from the Australian Capital Territory, Northern Territory and Tasmania (A7). The participant citrus growers of this study represented the major citrus growing regions in Australia such as the Riverina (NSW), the Murray Valley (NSW and VIC) the Riverland (SA), Queensland (QLD) and Western Australia (WA) (Sette et al., 2011; ABS, 2011) (Table 6.5).

Table 6.5: The surveyed growers' characteristics (demographics).

Questions A1, A3, A4, A5 and A7. (n = 72, Users, 35 and Non-users, 37)

Variables	n	Missing	Commercial BCAs		Total
			Users	Non-users	
A1	**72**	0			
Grower's role in orchards					
Owner			23	29	52
Manager			9	6	15
Other			3	2	5
Total			**35**	**37**	**72**
A3	**72**	0			
Levels of education					
Secondary			13	12	25
TAFE/Technical/Agricultural College			7	10	17
University			15	14	29
Others			0	1	1
Total			**35**	**37**	**72**
A4	**72**	0			
Age group					
25–29 years			1	1	2
30–34 years			2	0	2
35–39 years			5	5	10
40–44 years			5	5	10
45–49 years			2	6	8
50–54 years			6	6	12
55–59 years			8	6	14
60–64 years			4	4	8
65 and over			2	4	6
Total			**35**	**37**	**72**
A5	**72**	0			
Gender					
Male			31	35	66
Female			4	2	6
Total			**35**	**37**	**72**
A7	**72**	0			
Farm location					
NSW			16	19	35
QLD			5	3	8
SA			8	10	18
VIC			2	3	5
WA			4	2	6
Total			**35**	**37**	**72**

The number of years of citrus growing experience ranged from a minimum of 4.5 to 63 years (A2, n = 72–1 missing). The mean (Mean ± SE) citrus growing experience was 23.4 ± 1.6 years. There was a slight difference between user (22.1 ± 2.5) and non-user (24.6 ± 2.1) groups.

6.3.2 Farm practices relevant to pest management

This section presents combined results from interviews and survey for Questions C14–C22 which varied in responses from n = 72 to n = 35 (Question 21 is for users only). It is likely that farm practices will influence the adoption of commercial BCAs. Intercropping, for example, can reduce the incidence of pests and diseases (Lithourgidis et al., 2011). It was important to collect data on various citrus farm practices. This section includes the following variables: crop types, intercropping, cover crops, IPM tools, decision making for pest management, economic thresholds and their measurement, use of pesticides, use of commercial BCAs, and monitoring biological control agents.

Often intercropping influences the adoption of commercial BCAs. Intercropping increases plant diversity and interferes with pest host-finding. It enhances the natural population of predators and parasitoids, as well as the effectiveness of commercial BCAs by providing food and shelter. However, both interviewed and surveyed citrus growers reported that intercropping was not widely used among users or non-users (Appendix 11, Question C14, n = 72–1 missing).

Only a few interviewed growers (2/9) were intercropping with other crops such as avocados and almonds. One of them reported that he mixes citrus with avocados:

> "We have a large mixture of citrus and avocados and we have a mixture of mainly Navel oranges with some mandarins."

The majority of the interviewed growers (7/9) have a mixture of different varieties of citrus. According to the soil types they planted different varieties such as limes, lemons, oranges, mandarins, navel oranges, valencia oranges and grapefruit within the orchard.

One of them said that:

> "We do vary the species, all the varieties within the orchards. So over the orchards we may have in one line four or five different varieties."

The relationship between intercropping and the adoption of commercial BCAs is not clear. Intercropping is not a well-researched management tool in citrus crops.

Cover crops provide food and shelter to natural biological control agents and commercial BCAs. They increase parasitism and predation and reduce pest management inputs. In this study, cover crops were widely used among the surveyed growers, with the vast majority using grasses (Appendix 11, Question C15, n = 72). Almost equal proportion of users (23) and non-users (22) used grasses as cover crops. More non-users used clovers as a cover crop (11) or kept bare earth (10) than users (clover, 4, or kept the earth bare, 7). Growers used grasses as cover crop for various reasons not only to enhance natural biological control agents or enhance commercial BCAs' effectiveness. Users were more likely to avoid clover as cover crops because different pests get benefit from these plants such as light brown apple moth. A few users kept the earth bare which indicates that they did not maintain a favourable environment for biological control agents.

The majority of the interviewed citrus growers (6/9) used commercial BCAs such as *Aphytis* spp. One user reported not needing to use chemical pesticides because there were lots of naturally occurring biological control agents (such as ladybirds, praying mantids, predatory mites and assassin bugs) on top of commercially released *Aphytis* spp. The remaining interviewed growers (3/9) either used chemicals or microbial biological control agents for disease control. The survey question (Table 6.6, Question C16) asked citrus growers about the use of different pest control techniques in IPM. Only 58 respondents answered Question C16 and the distribution of users and non-users was 34 and 24 respectively.

The vast majority (45) used conservation biological control (C16 2) and users (29) are more likely to use this strategy than non-users (16). Conservation biological control is modification of the environment or existing practices to protect and enhance natural enemies or organisms to reduce the effect of pests. Similar numbers of users (22) and non-users (17) used chemical control (C16 3). Almost all participants (48) used monitoring. Only two of the users did not use monitoring (out of 31), and none of the non-users (out of 19). A similar trend was evident with insect traps, the users (21) and non-users (13) using them. A few of the surveyed citrus growers (in a total of 10 for users and non-users) used cultural practices (such as crop rotation or tillage).

The augmentative biological control (augmentative biological control is the method where commercial BCAs are introduced periodically to suppress the pests) showed contradictory results possibly because of the lack of understanding of the term. Some of the commercial BCA users ticked “NO” (five responses) and some other non-users ticked “YES” (five responses). In both cases these data were not included for this question (C16 4) analysis. This result demonstrates that growers used most of the pest control techniques in IPM but the question remains as to what level they practice these techniques.

Table 6.6: Different IPM tools used by the citrus growers (n = 72, Users, 35 and Non-users, 37).

Question C16 (n = 58, Users, 34 and Non-users, 24)

Variables		n	Missing	Yes	No	Total
C16 1		**38**	34			
Cultural control	Users			6	18	24
	Non-users			4	10	14
	Total			**10**	**28**	**38**
C16 2		**51**	21			
Conservation biological control	Users			29	1	30
	Non-users			16	5	21
	Total			**45**	**6**	**51**
C16 3		**49**	23			
Chemical control	Users			22	6	28
	Non-users			17	4	21
	Total			**39**	**10**	**49**
C16 4		**10***	36	5*	5*	10*
Augmentative biological		**26**				
control	Users			19	0	19
	Non-users			0	7	7
	Total			**19**	**7**	**26**
C16 5		**50**	22			
Monitoring	Users			29	2	31
	Non-users			19	0	19
	Total			**48**	**2**	**50**
C16 6		**41**	31			
Insect traps	Users			21	4	25
	Non-users			13	3	16
	Total			**34**	**7**	**41**
C16 7		**18**	54			
Others	Users			4	4	8
	Non-users			4	6	10
	Total			**8**	**10**	**18**

*Excluded from the analysis.

Users were more likely to perceive that the use of a consultant is important for making pest management decisions (Question C17, n = 72–1 missing). Users had a wide variety of decision makers such as owner and consultant (11), owner and manager (6), owner (6), manager (5), or manager and consultant (5). In contrast, most non-users (22) made their pest management decision by themselves (Figure 6.1). Perhaps they could not afford to hire a consultant because they were a small farm owner and achieve less money than the user growers. Pest management decision making is strongly dependent on economic factors.

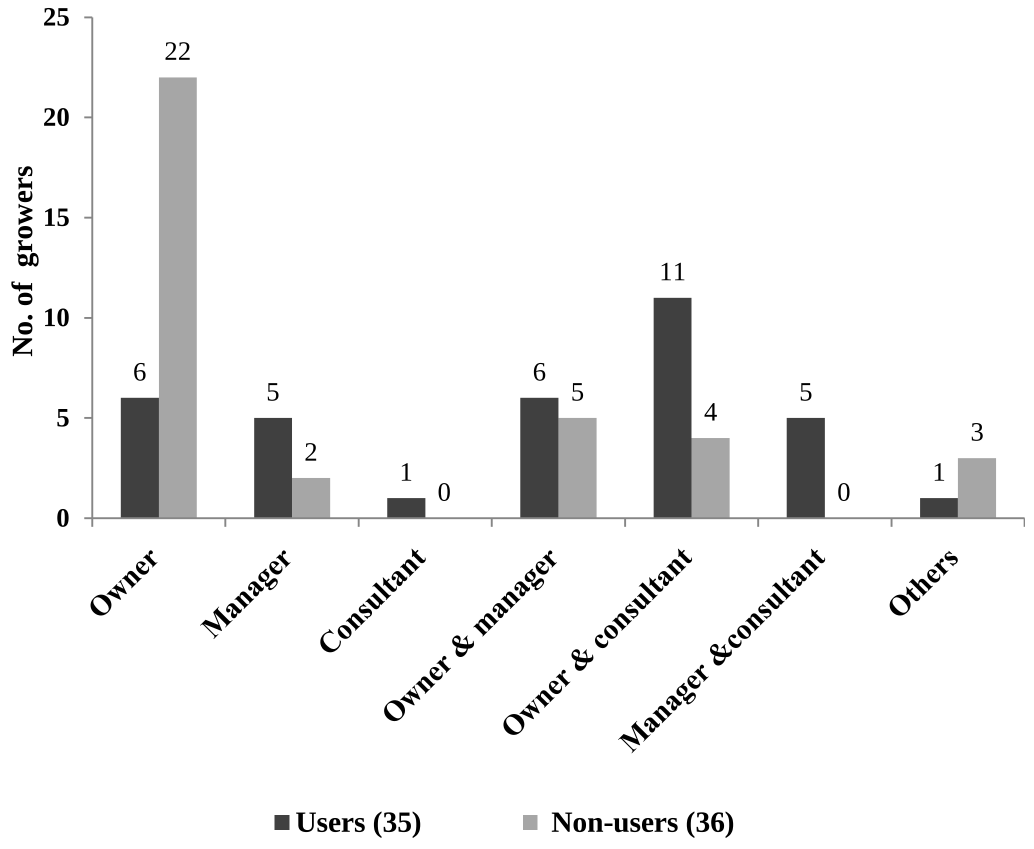

Figure 6.1: The decision maker for citrus pest management (Question C17, n = 72–1 missing). The numbers shown above each bar indicates the number of responses.

The economic threshold is an essential component in making a pest management decision. Almost all of the surveyed citrus growers (Question C18, n = 72–2 missing, users, 34 and non-users, 36) followed economic thresholds (52) when they make pest management decisions. Compared with the non-users (25) slightly more users (27) followed economic thresholds (Appendix 11, Question C18 for detailed summary statistics). Most of them (users and non-users) measured economic thresholds by monitoring (29 out of 49 respondents), while a few of them depended on consultants (7). Slightly more non-users (16) used monitoring than users (13) (Appendix 11, Question C19 for detailed summary statistics). Economic threshold is an important factor for any type of pest management, chemical pesticide or IPM based and users follow economic thresholds because success or failure of commercial BCAs is dependent on it.

The survey question C20 (n = 58, users, 30 and non-users, 28) asked citrus growers about use of different types of chemicals used in pest control. Chlorpyrifos (organophosphate) is a broad spectrum, non-selective insecticide and a widely used chemical by the surveyed citrus growers (totalling 38, users, 18 and non-users, 20). Non-users are more likely to used broad spectrum insecticides including: Ambush (permethrin) (2), Diazinon (organophosphate) (1) and Fipronil (phenylpyrazole) (1). In contrast, selective insecticides such as Movento (spirotetramat) (11), Petroleum oils (21) and Spinosad (organic insecticides) (5) were chosen by users. Users choose selective insecticides which are strongly associated with the use of commercial BCAs.

The survey provided understanding about the use of chemical pest control by citrus growers. Reasons given for the use of chemical pesticides by both users and non-users were to prevent damage: direct, cosmetic or both (Question D24, n = 58, users, 29 and non-users, 29) (Appendix 11, Question D24 for detailed summary statistics). This result indicates that commercial BCAs are not able to provide the level of pest control that citrus growers expected.

There was a wide acceptance of the need for chemical insecticide use by both users and non-users but they were both less likely to apply them according to a calendar or schedule (Question D26, n = 66, users, 32 and non-users, 34) (Appendix 11, Question D26 for detailed summary statistics). The surveyed users generally agreed (A and SA) that they applied insecticides when pests met economic thresholds (22) but they rotate the insecticides based on their modes of action (22) and site specific application (29). Non-users tried to reduce use of insecticides by variable rate (13) and site specific application (28).

The survey question C21 (n = 40, users, 32 and non-users, 8) asked commercial BCA user growers only to reply, but eight non-users answered. These eight were not considered. All user respondents (32) used *Aphytis* spp. (wasp parasitoid) to control red scales. A few of them (2) also used *Cryptoleamus montrouzi*eri (predator) to control mealy bugs and scale insects. Two user growers used *Mallada signata* (green lacewing) to control Kelly's citrus thrips and light brown apple moth. The growers who do not use C. *montrouzi*eri and *M. signata* or other commercial BCAs for citrus pests do not know about them or they are not very effective or too expensive.

Monitoring of biological control agents is a crucial part of using commercial BCAs. Both users and non-users were likely to find the biological control agents such as parasitoid wasps, predatory ladybirds, mites and lacewings (Table 6.7, Question C22).

Table 6.7: Citrus growers who found biological control agents in their orchards when they monitored their orchard (n = 72, Users, 35 and Non-users, 37).

Question C22 (n =46, Users, 26 and Non-users, 20)

Variables	n	Missing	Never	Rarely	Sometimes	Very often	Always	Total
C22 1 **Found parasitic wasps**	**45**	27						
Users			1	2	5	12	6	26
Non-users			1	0	5	9	4	19
Total			**2**	**2**	**10**	**21**	**10**	**45**
C22 2 **Found predatory ladybirds**	**41**	31						
Users			0	2	7	9	5	23
Non-users			0	0	6	7	5	18
Total			**0**	**2**	**13**	**16**	**10**	**41**
C22 3 **Found predatory mites**	**35**	37						
Users			1	2	5	11	4	23
Non-users			0	1	3	6	2	12
Total			**1**	**3**	**8**	**17**	**6**	**35**
C22 4 **Found hoverflies**	**32**	40						
Users			7	4	3	4	1	19
Non-users			3	3	0	5	2	13
Total			**10**	**7**	**3**	**9**	**3**	**32**
C22 5 **Found lacewings**	**44**	28						
Users			3	1	4	9	7	24
Non-users			1	2	4	9	4	20
Total			**4**	**3**	**8**	**18**	**11**	**44**

6.3.3 Economic characteristics/factors

The summaries of survey response to Questions A6, B8 and B9 are in Table 6.8 and are about: number of employees, farm size, and average gross value of citrus production per year. The three questions have n = 70 (A6), n = 72 (B8) and n = 70 (B9).

Table 6.8: Summary statistics of the economic factors (number of employees A6, farm size B8 and crop values per year B9) (n = 72, Users, 35 and Non-users, 37).

Variables	n	Missing	Commercial BCAs		Total
			Users	Non-users	
A6	**70**	2			
Number of full-time employees					
Less than one employee			6	10	16
1–5 employees			14	18	32
6–10 employees			4	4	8
11–20 employees			4	3	7
More than 20 employees			5	2	7
Total			**33**	**37**	**70**
B8	**72**	0			
Farm size					
Less than 10 ha			3	6	9
10–20 ha			6	11	17
20–30ha			3	6	9
30–40ha			2	2	4
More than 40 ha			21	12	33
Total			**35**	**37**	**72**
B9	**70**	2			
Crop value per year					
AUD$100,000–200,000			8	16	24
AUD$201,000–300,000			4	5	9
AUD$301,000–400,000			1	3	4
AUD$401,000–500,000			2	2	4
AUD$501,000–600,000			2	2	4
AUD$601,000–700,000			0	1	1
AUD$701,000–800,000			1	1	2
More than AUD$800,000			16	6	22
Total			**34**	**36**	**70**

The number of employees is related to the adoption of commercial BCAs. Most of the interviewed citrus growers (6/9) have 1–7 full-time employees. Only a few of them (3/9) have more than ten full-time employees. In surveyed growers (Table 6.8, Question A6) the most common number of full-time employees per farm was 1–5 people (32, users, 14 and non-users, 18). Sixteen growers (6 users and 10 non-users) have farms with less than one employee. Only 5 non-users have 11–20, or more than 20 employees and 9 users have the same number of employees.

Farm size is an important factor that strongly influences the adoption of commercial BCAs. The majority of the interviewed user growers (6/9) have more than 60 hectares of land under citrus orchards and non-users (3/9) have less than 30 hectares. The survey result (Table 6.8, Question B8) showed that slightly more growers have less than 40 hectares of land (39, users, 14 and non-users, 25) under citrus orchards. This result was consistent with the national data (most of the citrus growers have less than 40 hectares of citrus orchards) (Sette et al., 2011). However, the remaining growers (33) with more than 40 hectare of citrus orchards are more users (21) than non-users (12). This result was representative of the national data of 141 citrus growers (out of 1867 only 141 citrus properties were more than 40 hectares) (Sette et al., 2011). Bigger producers are users and more participated in this survey. Most of the non-users have small citrus farms and they were less likely to participate in this survey. This indicates that small farm owners are less likely to adopt commercial BCAs. They have fewer employees, could not afford a consultant or had other economic constraints.

The adoption of commercial BCAs is largely dependent on the size of the farm. The survey of citrus growers (n = 70) gave estimated gross value per year of citrus production (Table 6.8, Question B9). Less than half of the surveyed growers (24) had an average of AUD$100,000–200,000 gross value per year from citrus production, while the other half (22) had more than AUD$800,000. This was not distributed equally between the users and non-users. The majority of users (16 out of 22) achieved over AUD$800,000 gross value per year. In contrast, the non-users (16 out of 24), achieved only AUD$100,000–200,000 annual gross values. Users received higher gross value per year because they have a large farm but whether it was related to the use of commercial BCAs or not was inconclusive. This study did not attempt to analyse the costs and profits analysis. This was one of the limitations of this study.

Source of income has a large impact on the adoption of commercial BCAs. Most of the interviewed citrus growers (7/9) reported that the citrus farm was their main source of income. Some citrus growers inter-crop with other higher value crops to diversify the sources of income. One of them reported that:

> "Because avocados are worth more money than citrus so I diversify into a different crop of avocados. I planted avocados strategically in places that are frost free, that are high, that will produce good quality fruits; as a viable crop, as a crop that will make more money than citrus."

Growers intercrop higher value crops to support their income but they modify the total cropping system in terms of habitat. This might be reduced pest pressure or perhaps a different pest pressure than the citrus orchards alone. This is an important issue for the adoption of commercial BCAs.

The summaries of survey responses given in Question B10 (Table 6.9), Question B11 (Figure 6.2) and Question B13 (Figure 6.3) are about: pest management expenses, crop losses incurred each year and acceptable to the growers, and market destination.

Pest management expenses may also affect the adoption of commercial BCAs. Interviewed user growers (6/9) spend on average AUD$8,000 on commercial BCAs and AUD$34,000 on chemical pesticides per year. On top of that they spend on average AUD$14,000 per year for a consultant. The surveyed users spent more on horticultural/mineral oils (AUD$8568±2733) and consultants (AUD$8144±2062) than the non-users (Table 6.9, Question B10). They spent slightly more on insecticides (AUD$13778±4450) and herbicides (AUD$10706±3145) than non-users (AUD$11080±4638 and AUD$8305±2129 respectively). On the other hand non-users spent more on miticides (AUD$12100±6809) and other tools (AUD$7400±6321) than users (AUD$4506±1856 and AUD$2384±1157 respectively). Users and non-users spent somewhat similar amounts on fungicides, Bt and monitoring. Thus users use more on consultants and oils but non-users use more miticides. The expenses for the remaining tools did not vary greatly between users and non-users. One of the limitations of this study was not to calculate these expenses per hectare due to the lack of data.

Table 6.9: Pest management expenses for different IPM tools (n = 72, Users, 35 and Non-users, 37).

Question B10, (n = 61, Users, 28 and Non-users, 33)

Pest management tools	n			Mean expenses ±SE (AUD$)
B10 2 Insecticides	**48**			
		Users	23	13778±4450
		Non-users	25	11080±4638
B10 3 Fungicides	**44**			
		Users	20	13741±6940
		Non-users	24	14050±7556
B10 4 Acaricides or Miticides	**15**			
		Users	8	4506±1856
		Non-users	7	12100±6809
B10 5 Herbicides	**54**			
		Users	25	10706±3145
		Non-users	29	8305±2129
B10 6 Bt (Dipel, Biobit, Condor etc)	**11**			
		Users	8	2215±700
		Non-users	3	2500±289
B10 7 Oil (Horticultural/Mineral oils)	**35**			
		Users	18	8568±2733
		Non-users	17	3389±880
B10 8 Consultants	**21**			
		Users	14	8144±2062
		Non-users	7	5614±2699
B10 9 Monitoring	**33**			
		Users	18	15487±6432
		Non-users	15	14460±6819
B10 10 Others	**8**			
		Users	5	2384±1157
		Non-users	3	7400±6321

Often crop type or crop varieties influence technology adoption. Almost all surveyed citrus growers grow oranges (69), and most of them (55) grow 51%–100% oranges (Appendix 11, Question C12 for detail statistics). The data are broadly consistent with the citrus industry statistics (www.oranges.com.au/industry/) where oranges (76%) were the most produced crop, than mandarins (16%) followed by lemons and limes (5.5%) and grapefruit (2.5%). In terms of each variety, both users and non-users grew almost the same proportion of citrus varieties except lime. More users (9) grew lime than non-users (3). This result reveals that choice of citrus variety does not have a major impact on the adoption of commercial BCAs.

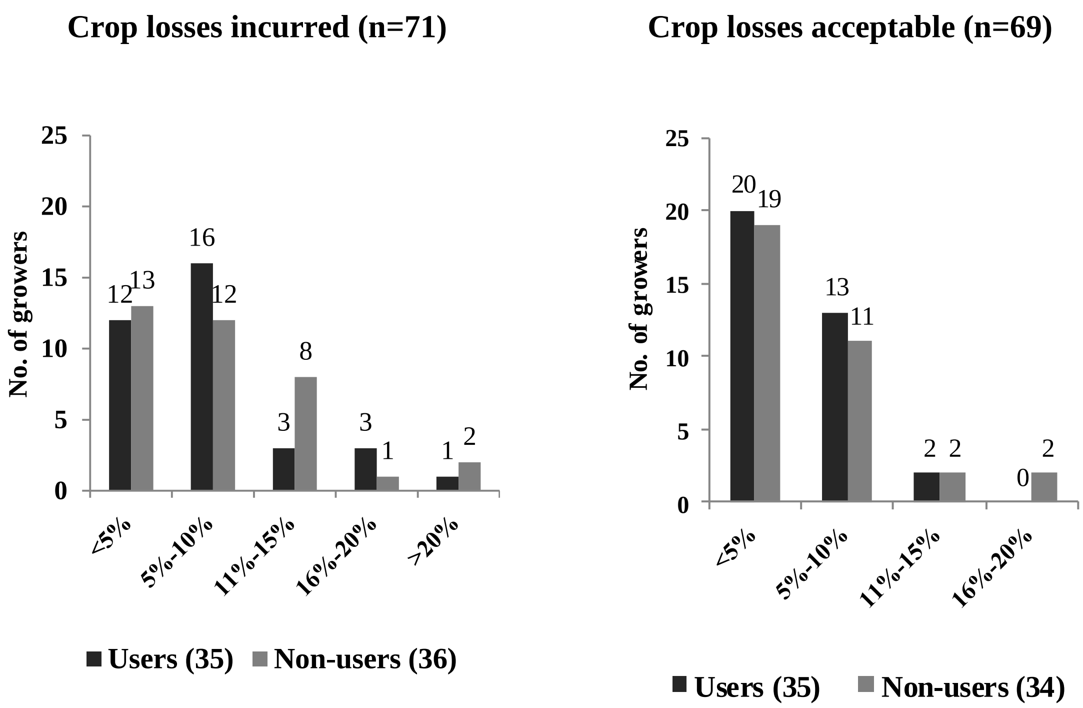

Figure 6.2: Level of crop losses incurred each year and acceptable to the citrus growers (question B11) (n = 72, Users, 35 and Non-users, 37). The numbers shown above each bar indicates the number of responses.

The use of commercial BCAs is associated with reduced crop losses (Figure 6.2, Question B11). Less than 5% crop losses were incurred each year by 25 surveyed citrus growers (users, 12 and non-users, 13) whereas, 28 growers (users, 16 and non-users, 12) incurred crop losses between 5%–10% each year. More non-users (8) incurred 11%–15% crop losses each year than users (3). This result shows that users reduced crop losses by using commercial BCAs. Up to 10% crop losses were considered acceptable to many surveyed citrus growers (users, 33 and non-users, 30). One of the limitations of this study is that it did not calculate the actual losses per growers due to the lack of data.

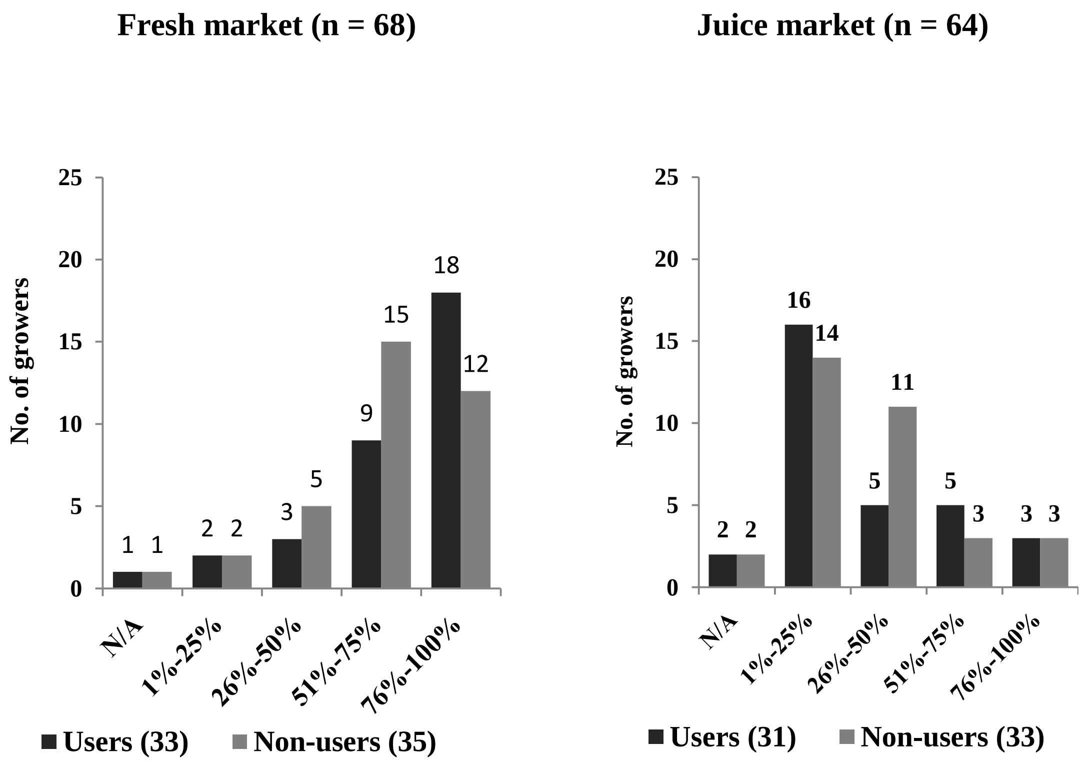

Figure 6.3: Market destination of the citrus crop (Question C13), (n = 72, Users, 35 and Non-users, 37). The numbers shown above each bar indicates the number of responses.

Market destination can influence the use of commercial BCAs (Figure 6.3, Question C13). More users (18) sent 76%–100% of the crop to the fresh market than non-users (12). In contrast, a higher number of non-users (15) sent 51%–75% of the crop to the fresh market than users (9). Slightly more users (16) sent 1%–25% of the crop to the juice market than non-users (14). More non-users (11) sent 26%–50% of the crop to the juice market than users (5). Thus market destination can influence growers' decision on the adoption of commercial BCAs because different markets have different pricing and required different levels of fruit quality or residue limits. Therefore, for the fresh market, growers are more likely to give more attention to their pest management practices than for the juice market. Overall, the economic characteristics of users and non-users of commercial BCAs are summarised below in Table 6.10.

Table 6.10: The characteristics of typical user and non-user citrus grower on the basis of economic factors.

Characteristics	Users	Non-users
Number of employees	Have more employees.	Have few employees.
Farm size	More than 40 hectares.	Less than 40 hectares or up to 40 hectares.
Crop values per year	Achieved more crop values per year.	Achieved less crop values per year.
Chemical uses	More likely to use selective chemicals.	More likely to use broad spectrum chemicals.
Crop losses	More likely to have 5%–10% crop losses.	More likely to have 11%–15% crop losses.
Market destination	Majority (18) sent produce to the fresh market. Only a few (6) sent to the juice market.	Most (15) sent produce to the fresh market and 10 growers sent to the juice market.

6.3.4 Institutional factors

Institutional factors such as sources of information and organisational help are crucial parts of the adoption of commercial BCAs. The main sources of information regarding commercial BCAs according to the interviewed citrus growers are: workshops, field days, other farmers, Horticulture Innovation Australia Ltd, Citrus Australia and consultants. Surveyed citrus growers seek information from a variety of sources (Table 6.11, Question F33). Slightly more users are more likely to perceive that workshops, field days, and insectary companies are the main information sources than non-users. Both users and non-users identified other growers and pamphlets as useful sources of information. Surveyed citrus growers pointed out that the internet, citrus news, consultants, and

The Good Bug Book were their sources of information. This result reveals that citrus growers use a wide range of information sources about the topic of pest management. There was no large variation apparent between the user and non-user group, apart from contact with insectary companies by users.

Table 6.11: Growers' sources of information on the topic of pest management (n = 72, Users, 35 and Non-users, 37).

Question F 33, (n = 65, Users, 34 and Non-users, 31)

Variables	n	Missing	Yes	No	Total
F33 1 Workshops	**58**	14			
Users			27	4	31
Non-users			22	5	27
Total			**49**	**9**	**58**
F33 2 Field days	**60**	12			
Users			28	2	30
Non-users			25	5	30
Total			**53**	**7**	**60**
F33 3 Pamphlets	**50**	22			
Users			21	3	24
Non-users			20	6	26
Total			**41**	**9**	**50**
F33 4 Other growers	**47**	25			
Users			17	5	22
Non-users			20	5	25
Total			**37**	**10**	**47**
F33 5 Insectary companies	**50**	22			
Users			25	2	27
Non-users			17	6	23
Total			**42**	**8**	**50**
F33 6 Haven't heard	**23**	49			
Users			0	12	12
Non-users			2	9	11
Total			**2**	**21**	**23**

Institutional support is an important factor because it creates a framework in which adoption can take place. Interviewed South Australian citrus growers (4/9) reported that no government extension officers exist anymore. Some government researchers did research in conjunction with an industry body such as Horticulture Innovation Australia

Ltd. They worked together and then the industry body released information to growers. Surveyed users and non-users (n = 65, users, 33 and non-users, 32) both disagreed (SD and D) with the statements that they received consultation (51, users, 26 and non-user, 25), monitoring services (50, users, 27 and non-users, 23) or subsidies for citrus orchards (54, users, 28 and non-users, 26) from the government (Appendix 11, Question F34 for detailed summary statistics). They agreed (A and SA) with the statements that they received consultation from the agricultural chemical companies (35, users, 18 and non-users, 17), insectary companies (36, users, 24 and non-users, 12) and other organisations (38, users, 16 and non-users, 22) (Question F34 2–4). They also disagreed (SD and D) with the statements that they received monitoring services from the agricultural chemical companies (45, users, 25 and non-user, 20), insectary companies (42, users, 23 and non-users, 19) or other organisations (27, users, 14 and non-users, 13) (Question F34 6–8). They agreed (A and SA) with the statements that they do not get any help from the government or other organisations except information (38, users, 19 and non-users, 19) (Question F34 11) but this contradicts with the information that they received consultation from the agricultural chemical companies, insectary companies and other organisations. Perhaps there was a flaw in the questionnaire because there was no other option for information only. This result indicates that citrus growers do not get any direct help from the government such as subsidy to their farm. They are not aware that the government is funding research projects in collaboration with industry bodies such as Horticulture Innovation Australia Ltd. to develop new or improved technology for them.

6.3.5 Citrus growers' perceptions of the main barriers towards the use of commercial BCAs

Growers' attitudes or perceptions are likely to be important factors that influence the uptake of commercial BCAs. In this study, both interviews and survey asked about attitudes or perceptions of the main barriers towards the use of commercial BCAs. In the survey, several Likert-type scaled questions were asked of the citrus growers. Each of the questions included several statements or items.

Citrus growers' perceptions about practicing IPM and the barriers they faced are summarised in Table 6.12 (Question D23, n = 66, users, 32 and non-users, 34). Users (18) and non-users (26) agreed (A and SA) with the statement that practicing IPM required more knowledge than conventional pest control. Compared with non-users, more users disagreed (SD and D) with the statements that practicing IPM required more time (22) and labour (20) than conventional pest control. Non-users believed (A and SA) that practicing IPM required more time (20) but remained undecided (U) about whether it required more labour (12). This result indicates that practicing IPM by citrus growers was hindered because non-users believed it requires more knowledge, time and labour.

In terms of economics, interviewed citrus growers (3/9) believed that using commercial BCAs is more expensive than chemical insecticide because commercial BCAs required expenses for monitoring and a consultant. Survey results showed that users are large farm owners and non-users are small farm owners (Table 6.8, Question B8). Perhaps a small farm owner could not afford to hire a consultant. In addition, one of the interviewed citrus growers said if *Aphytis* spp. is used with chemicals then that makes it significantly more expensive than chemicals alone. In contrast, the application of one chemical could do the job of several BCAs and therefore is simpler and cheaper. The survey question D27 was asked only to non-users to know their attitudes towards the use of commercial BCAs. The responses were compared by the agreement and disagreement of non-users. The users who answered (8) were ignored.

Table 6.12: Citrus growers' perception about practicing IPM compared with conventional practices (n = 72, Users, 35 and Non-user 37).

SD= Strongly Disagree, D=Disagree, U=Undecided, A=Agree and SA= Strongly Agree.

(Question D23, n = 66, Users, 32 and Non-users, 34).

Variables	n	Missing	SD	D	U	A	SA	Total
D23 1 Requires more time	**66**	6						
Users			8	14	2	6	2	32
Non-users			2	5	7	17	3	34
Total			**10**	**19**	**9**	**23**	**5**	**66**
D23 2 Cost more	**64**	8						
Users			7	15	4	3	2	31
Non-users			5	11	8	6	3	33
Total			**12**	**26**	**12**	**9**	**5**	**64**
D23 3 Requires more knowledge	**64**	8						
Users			2	9	2	13	5	31
Non-users			1	3	3	20	6	33
Total			**3**	**12**	**5**	**33**	**11**	**64**
D23 4 Requires more labour	**64**	8						
Users			8	12	5	4	2	31
Non-users			3	9	12	6	3	33
Total			**11**	**21**	**17**	**10**	**5**	**64**

Surveyed non-users remained undecided (U) with the statements that commercial BCAs are expensive and not profitable (Tables 6.13, Question D27 4–5) but disagreed (D) with the statement that it is wasteful to use both chemicals and commercial BCAs together (Table 6.13, Question D27 13). They remained undecided (U) with the statement that chemicals are cheaper (Table 6.13, Question D27 12). Perhaps these non-users did not try commercial BCAs previously to compare and remained undecided. Interview results show that this is one of the technological complexities that make commercial BCAs expensive. This is one of the major economic barriers to the adoption of commercial BCA.

Table 6.13: Economic barriers to the adoption of commercial BCA by citrus grower. This question was for NON-USERS only (n=37).

SD= Strongly Disagree, D=Disagree, U=Undecided, A=Agree and SA= Strongly Agree.

(Question D27, Non-users = 23)

Variables		n	Missing	SD	D	U	A	SA	Total
D27 2 Not confident	Non-users	**23**	14	1	4	10	4	4	23
D27 4 Too expensive	Non-users	**23**	14	0	2	11	6	4	23
D27 5 Not profitable	Non-users	**22**	15	0	7	9	4	2	22
D27 7 Too risky	Non-users	**22**	15	0	7	7	4	4	22
D27 12 Chemicals are cheaper	Non-users	**23**	14	1	5	10	4	3	23
D27 13 Wasteful to use both chemicals and commercial BCA together	Non-users	**22**	15	4	7	5	5	1	22

A small number of interviewed citrus growers (2/9) perhaps used commercial BCAs (*Aphytis* spp.) for higher value crops such as the Navel variety. Results showed that slightly higher numbers of surveyed non-users believed that commercial BCA is a more risky decision (Table 6.13, question D27 7) and perhaps they were less likely to use commercial BCAs for higher value crops. This demonstrates that lack of confidence by growers is a key reason for not using commercial BCAs.

Technology complexity is an important factor because it is often negatively related to the adoption. The timing of pesticide application and release of commercial BCAs (*Aphytis* spp.) are critical to effective pest control. Interviewed citrus growers were asked whether they faced any difficulties when they use commercial BCAs and pesticides together for pest control. Most of them (6/9) pointed out that they did not because they allow time to elapse between the use of commercial BCAs and pesticide application. Only a few citrus growers (2/9) spray pesticides within 30 days after the release of commercial BCAs. Other growers spray twice in a year. Some do not spray any chemicals at all. Surveyed users were aware about the effects of insecticides on commercial BCAs. They (13) also reported that they delay the application of pesticides more than five weeks after the release of commercial BCAs (Appendix 11, Question E32 for detailed summary statistics) to allow enough time between pesticide application and releasing commercial BCAs. The application of pesticide and commercial BCAs is more difficult as a pest management strategy.

Some technology related statements from the survey Questions D27 and E31 are shown in Table 6.14 and Table 6.15. The D27 question is for non-users and the E31 is for users only. These statements were used in this study, as potential technological barriers to the adoption of commercial BCAs. The responses from the non-users were only considered in question D27. Non-users agreed (A and SA) that they have tried *Aphytis* spp. before but they were not effective (9), too complicated (8), chemicals are more effective (12) and need to hire a consultant (11). They disagreed (SD and D) that it is wasteful to use commercial BCAs and chemical insecticides together (Table 6.13, Question D27 13).

Users disagreed (SD and D) with the statements (Table 6.15, E31 1–4 and 6) that no commercial BCA is available for pests other than red scales (18); *Aphytis* spp. control red scales in certain citrus varieties (22), need training (19) and a consultant (14); agreed (A and SA) that *Aphytis* spp. attack a certain stage of red scales (17).

These views showed non-users' negative attitudes and users' positive attitudes towards the use of commercial BCAs for pest management. The fundamental technological barriers that citrus growers face to the adoption of commercial BCAs for pest management are also identified.

Table 6.14: Technological barriers to the adoption of commercial BCA. This question was for NON-USERS only (n=37).

SD= Strongly Disagree, D=Disagree, U=Undecided, A=Agree and SA= Strongly Agree.

(Question D27, Non-users = 23)

Variables		n	Missing	SD	D	U	A	SA	Total
D27 3 Tried before not effective	Non-users	**22**	15	0	7	6	6	3	22
D27 6 Too complicated	Non-users	**23**	14	1	5	9	7	1	23
D27 10 Need to hire a consultant	Non-users	**21**	16	1	4	5	7	4	21
D27 11 Chemicals are more effective	Non-users	**21**	16	2	1	6	10	2	21

Availability of commercial BCAs is another important factor. Most of the interviewed citrus growers (6/9) pointed out that *Aphytis* spp. is the only biological control agent that is commercially available for control of red scale in citrus crops but they face other major pest problems besides red scales. They have been forced to use chemicals to control multiple pests. These interviewed citrus growers may not be aware that other commercial BCAs are available for citrus pests such as *C. montrouzi*eri to control mealy bugs and scale insects. The survey results show that greater awareness to commercial BCAs for other pests than red scale (Table 6.15, Question E31 1). Perhaps growers mean commercial BCAs that control other pests in other crops.

Table 6.15: Technological barriers to the adoption of commercial BCA. This question was for USERS only (n=35).

SD= Strongly Disagree, D=Disagree, U=Undecided, A=Agree and SA= Strongly Agree.

(Question E31, Users = 32)

Variables		n	Missing	SD	D	U	A	SA	Total
E31 1		**31**	4						
No commercial BCA available for other pest other than red scales	Users			2	16	8	3	2	31
E31 2		**30**	5						
***Aphytis* spp. only attack certain stages of red scales**	Users			2	4	7	13	4	30
E31 3		**29**	6						
***Aphytis* spp. control red scales only certain citrus varieties**	Users			7	15	5	2	0	29
E31 4		**30**	5						
Need training before use commercial BCAs	Users			5	14	5	6	0	30
E31 6		**30**	5						
Need a consultant to use commercial BCA	Users			4	10	5	9	2	30

The time lag between release of a commercial BCA and actual impact on the pest population can cause economic damage. One of the growers believed that this was probably the major issue. Growers need to monitor pests closely and to have patience and confidence with commercial BCAs because instant results are not visible. Perhaps users were more likely to perceive that economic damage is unavoidable to some extent and as a result gave emphasis on monitoring and levels of confidence in commercial BCAs. Perhaps these deterred growers from adopting commercial BCAs.

The timing of the release of commercial BCAs is crucial for its effectiveness. For example, *Aphytis* spp. attacks only a certain stage of red scales, as agreed by users (Table 6.15, Question E31 2). Growers have to understand by monitoring whether the release is good for the stage of scale development. This demonstrates that monitoring is essential for the commercial BCAs but also for the natural population of pests and biological control agents as well. One interviewed grower also stated that the most successful release time for the commercial BCA, *Aphytis* spp. would be in the autumn because there is overlapping generations of pest insects. In winter there is a distinct generation which means only a narrow window during which the parasitoid (*Aphytis* spp.) finds red scales to parasitise. Pest densities are important for successful introduction of commercial BCAs which ultimately determines success or failure of these agents.

The key locational effect identified by this study was Queensland (further north than other states) where citrus growers cannot use conventional pest management. They have to use the commercial BCA, *Aphytis* spp. because pests (red scales) grow throughout the year and develop resistance to chemical pesticides very quickly. This demonstrates that the adoption of commercial BCAs depends on the climate such as temperature because the type and intensity of pest pressures in the orchards have regional impacts and are largely influenced by the climate.

In terms of habitat management, interviewed growers know that using commercial BCAs is more complicated than chemical based conventional practices and know that expertise is required for the use of BCAs. A few of them (2/9) pointed out that commercial BCAs is not easy to use in terms of habitat management because growers need to know about how other things work in the orchards. They need to maintain favourable orchard habitat for commercial BCAs. They need to understand what insects cause damage to a crop at different times of year and assess what environmental conditions are necessary for successful use of commercial BCAs. In surveyed responses, non-users (9) remained undecided (U) and agreed (A and SA) (8) that using commercial BCAs is too complicated (Table 6.14, Question D27 6). They agreed with the statements that it is necessary to hire a consultant (11) (Table 6.14, Question D27 10) which demonstrates that using commercial BCAs requires careful management.

Growers' attitudes are important because often growers are conservative and reluctant to change their pest management practices. Some interviewed citrus growers (3/9) believe that biological control agents are not effective. The surveyed results showed that non-users agreed (A and SA) that chemicals are more effective (12) (Table 6.14, Question D27 11). Perhaps in the past they tried to change their practices but were not successful and fruit quality and production dropped (Table 6.14 Question D27 3). In addition, they were afraid that if their production went down and most of their fruit had to be sold for juice then they will not get the same value per ton of fruit.

Often biosecurity issues increase the complexity of pest management. One of the interviewed growers pointed out that the presence of Queensland fruit fly is a trade barrier for some markets. No commercial BCAs are available for this pest so growers are forced to use insecticides. This makes the commercial BCA (*Aphytis* spp.) for red scale vulnerable because insecticides are also toxic to the parasitoids. This result reveals that biosecurity created a critical situation for the growers. Growers face a major conflict which is most likely to hinder the adoption of commercial BCAs.

6.3.6 Citrus growers' perceptions of the main driving factors towards the use of commercial BCAs

In this study, both interviews and survey measured citrus growers' attitude or perception of the main driving factors towards the use of commercial BCAs. In the survey, several Likert-type scaled questions were asked the citrus growers. Each of the questions included several statements or items. Several positive statements of the commercial BCAs were from the survey Questions D25, D28 and D29 are shown in Table 6.17, 6.18 and 6.16, (Questions D25, D28 and D29). This section presents the results below:

Economic factors have an important influence on growers. Interviewed users (9/9) said that commercial BCAs are cheaper than chemical control. Initially it may be more expensive but once it is working properly it would be still less expensive than chemical pesticides. In addition, using IPM protects other beneficial insects that are already present in the orchards. One of them explained why he uses IPM:

> "It's cost wise and also to protect the good bugs that have already got on the property."

The survey question D29 asked only users and they agreed (A and SA) that it is relatively cheap (15) and profitable (20) (Table 6.16, Question D29 3–4). This result reveals that due to economic reasons, citrus growers are more likely to incorporate commercial BCAs into their pest management program because it is cheaper than chemicals and protects other beneficial insects. This study also reveals that users are large producers, have more employees and are more likely to use commercial BCAs. Therefore, all of these factors suggest that economic factors are the main reasons to adopt commercial BCAs by citrus growers.

Both insecticide resistance and insecticide withdrawal are well researched driving factors around the world. These two factors have forced growers to adopt alternative pest control practices such as IPM. The survey asked questions of the users regarding these issues by using Likert-type scaled questions. Users disagreed (SD and D) with the statements that pest insects have developed resistance (14) and an insecticide was withdrawn (19) (Table 6.16, Question D29 1–2). In this study, these were seen as potential driving factors for the adoption of commercial BCAs. This result reveals that perhaps surveyed citrus growers did not face these problems and viewed only their individual situation not the historical or worldwide views.

Table 6.16: Economic and technology driving factors to the adoption of commercial BCA. This question was for USERS only (n=35).

SD= Strongly Disagree, D=Disagree, U=Undecided, A=Agree and SA= Strongly Agree.

(Question D29, Users = 32)

Variables		n	Missing	SD	D	U	A	SA	Total
D29 1		**30**	5						
Insects have developed resistance	Users			2	12	6	6	4	30
D29 2		**29**	6						
Insecticide was withdrawn	Users			3	16	4	4	2	29
D29 3		**28**	7						
It is profitable	Users			2	2	4	15	5	28
D29 4		**28**	7						
It is relatively cheap	Users			2	6	5	11	4	28
D29 5		**30**	5						
It is effective	Users			1	0	4	20	5	30
D29 6		**29**	6						
It helps IPM	Users			1	0	1	20	7	29

Citrus growers were convinced by a range of other factors to use commercial BCAs. The survey results showed (Table 6.17, Question D25 2–3 and D25 5) that users were more likely to perceive (A and SA) that chemicals kill some (26) or most (16) beneficial insects or change their effectiveness (19). Perhaps this type of awareness influenced them to use commercial BCAs. One of the interviewed citrus growers reported that he was convinced by his education and knowledge to use commercial BCAs. He also reported that many of them knew that the commercial BCA, *Aphytis* spp. is effective. They achieved very good control and a safe and sustainable environment for growing crops. They were forward thinkers and know that it will not be sustainable to use chemicals for a long time. They also know that in future people will buy fruit and vegetables with fewer chemicals. The surveyed users agreed (A and SA) that they were convinced by their education (28) (Table 6.18, Question D28 1). They were also concerned about the environmental risk

(25) and agreed (A and SA) that it is safe for the environment (27) (Tables 6.18 and 6.19, Question D28 5 and D29 8). This result indicates that educated and forward thinking growers were more likely to use commercial BCAs and were concerned about commercial BCA's effectiveness, food safety and the environment where they were growing their crops.

Health issues are a factor and a few of the interviewed growers (3/9) realised that there were no residue problems when fruits go to market and were safe for health reasons. No one became sick due to the use of pesticide on their farms but one of them was convinced to adopt biological control because a previous owner working with chemicals became sick with cancer. One farm manager was afraid of chemicals and was convinced to use biological control. However, the owner of that farm was doubtful about its effectiveness and took 3–4 years to feel comfortable with using biological control as a management tool.

Table 6.17: Driving factors for the adoption of commercial BCA (n =72, Users, 35 and Non-users, 37). In this table, the abbreviation BCA indicates Biological Control Agents**.**

SD= Strongly Disagree, D=Disagree, U=Undecided, A=Agree and SA = Strongly Agree.

Questions D25 (n = 65, Users, 32 and Non-users, 33)

Variables		n	Missing	SD	D	U	A	SA	Total
D25 2		**57**	15						
Chemicals killed most of the BCAs	Users			0	9	3	12	4	28
	Non-users			2	9	8	8	2	29
	Total			**2**	**18**	**11**	**20**	**6**	**57**
D25 3		**56**	16						
Chemicals Killed some of the BCAs	Users			0	1	0	22	4	27
	Non-users			1	2	2	21	3	29
	Total			**1**	**3**	**2**	**43**	**7**	**56**
D25 5		**55**	17						
Chemicals changed BCA effectiveness									
	Users			1	2	4	13	6	26
	Non-users			1	2	5	18	3	29
	Total			**2**	**4**	**9**	**31**	**9**	**55**

Table 6.18: Driving factors for the adoption of commercial BCA. This question was for USERS (n=35) only.

SD= Strongly Disagree, D=Disagree, U=Undecided, A=Agree and SA = Strongly Agree.

(Question D28, Users, 32)

Variables		n	Missing	SD	D	U	A	SA	Total
D28 1		**31**	4						
Convinced by my education	Users			0	2	1	20	8	31
D28 4		**30**	5						
Concerned about health risks	Users			2	2	4	16	6	30
D28 5		**30**	5						
Concerned about the environment	Users			1	1	3	18	7	30

The surveyed users were concerned about health risks (22) and agreed (A and SA) that it is safer for the health of himself and his family (27) (Tables 6.18 and 6.19, Question D28 4, D29 7). This result demonstrates that growers are concerned about their personal health issues which convinced them to use commercial BCAs. Managers are more aware about health and safety than owners; owners are more concerned about profit and less about health and safety.

Table 6.19: Driving factors for the adoption of commercial BCA. This question was for USERS (n=35) only.

SD= Strongly Disagree, D=Disagree, U=Undecided, A=Agree and SA = Strongly Agree.

(Question D29, Users = 32)

Variables		n	Missing	SD	D	U	A	SA	Total
D29 7		**30**	5						
Safer for health of me and my family	Users			2	0	1	18	9	30
D29 8		**31**	4						
Safer for the environment	Users			2	0	2	18	9	31

Consumer education is another driving factor because they can drive retailers to demand pesticide-free fruit and vegetables. In addition, technology itself and policy makers can act as drivers. One of the interviewed citrus growers said that growers are prepared to use 100% biological control if consumers would buy blemished fruit. Another interviewed grower felt that it is necessary to educate consumers that blemished fruit is not bad. It still looks and tastes the same inside the protective skin. He also felt that education would be necessary for all other horticultural products.

The surveyed non-users agreed (A and SA) that if: consumers accept blemishes in fruit and vegetables (23), retailers put on pressure to use biological control (19), a suite of commercial BCAs are available for all the pests (20), the commercial BCAs become cheaper and more effective (24), and the government creates new laws to use biological control (20) then growers will use commercial BCAs as a pest management tool (Table 6.20, Question D30).

Table 6.20: Non-users' attitudes towards the use of commercial BCA for pest management in future. This question was for NON-USERS only (n=37).

SD= Strongly Disagree, D=Disagree, U=Undecided, A=Agree and SA= Strongly Agree.

(Question D30, Non-users = 30)

Variables		n	Missing	SD	D	U	A	SA	Total
D30 1 **If consumers accept blemishes in fruits and vegetables**	Non-users	**29**	8	1	3	2	17	6	29
D30 2 **If a suite of biological agents available for all the pests**	Non-users	**30**	7	2	4	4	14	6	30
D30 3 **If the biological control agents become cheaper and more effective**	Non-users	**30**	7	0	3	3	17	7	30
D30 4 **If retailers put pressure on growers to use biological control agents**	Non-users	**29**	8	2	2	6	16	3	29
D30 5 **If the government creates a new law to use biological control agents by growers**	Non-users	**29**	8	4	2	3	18	2	29

These statements uncovered some potential barriers that deterred citrus growers from the use of commercial BCAs. This result also reveals the need to address these issues by insectary owners and policy makers. It will lead to a decrease in pesticide use and an increase in commercial BCAs as a pest management tool.

6.4 Discussion

The release of commercial BCAs for insect pest control is not a stand-alone practice. It is always used as a tool in IPM programs. In this study, non-users were more likely to believe that practicing IPM required more knowledge, time, and labour in comparison with users. These are perhaps the major barriers to the adoption of IPM and thus commercial BCAs. It is necessary to follow IPM to implement a commercial BCA as a tool to contribute to better pest control.

Adoption is a dynamic learning process and depends on a range of personal, social, cultural, and economic factors as well as the characteristics of the technology (Pannell et al., 2006). Using commercial BCAs is a scientifically feasible strategy in IPM to control pests but economic viability for the grower depends on the cost and benefit in relation to the use of the crop produced. A wide range of factors has impact on the expected costs and expected benefits before the adoption decision is made.

The interview and survey results reveal that economic factors have a major impact on the adoption of commercial BCAs in IPM programs. There were strong differences between users and non-users. Most of the users were large producers (more than 40 hectares of land under citrus production), likely to have more full-time employees, at least 11 and some more than 20, and achieved more than AUD$800,000 gross value per year from citrus production. In contrast, most non-users were small farm owners (less than 40 hectares of land under citrus production), have fewer employees (1–5) and achieved less than AUD$100,000–200,000 gross value per year from citrus production. This result also shows that 12 large growers were non-users and 14 small growers were users. Several other reasons may be involved such as perhaps these large growers did not have consultant or farm managers, were not well educated about commercial BCAs or did not face too much red scales problems. Perhaps the opposite happened in the small growers are, as a result they were users. This distribution is strong, so in the following section the term user can be employed to represent large farm owners and non-user can be used for small farm owners.

Small farm owners generally have limited resources relative to the larger farm owners. They believe adoption of commercial BCAs to be a major challenge because of the increased requirements for specialised expertise required for the successful use of commercial BCAs. They are less likely to invest money in either growing their crop or purchasing the expertise to assist in growing their crop. Small farm owners with low on-farm income tend to seek sources of off-farm income and give less importance to the actual farm income. Another reason may be because the small scale production with limited time, effort and other resources means that they could not produce export quality products and enter into the profitable export market. They have to sell their product into the local market but that market is not very remunerative. As a result, they achieved less revenues and had limited chance to invest for adoption of commercial BCAs (Bijman et al., 2007).

For the large farm owners the present results are generally consistent with other studies. The large farm owners were more likely to adopt a new technology (Feder et al., 1985;

Fernandez-Cornejo, 1996; Shennan et al., 2001; Grogan and Goodhue, 2012; Akudugu et al., 2012). For instance, in the California citrus growers survey (2010), growers were more likely to use commercial BCAs when they have large citrus farms or hire more full-time workers (Li et al., 2011; Grogan and Goodhue, 2012). Perhaps Californian and Australian farming systems with large farms are similar. Perhaps small farm owners did not use farming as a main source of income and it was not possible to address this issue by follow-up email or telephone calls because the survey was anonymous.

Other researchers argued that there was no relationship between farm size and adoption of new technology (Schumacher and Marsh, 2003; Kaine and Bewsell, 2008; Marsh and Gallardo, 2009). For instance, there was no relationship between farm size and adoption of IPM among different crop growers such as tomato, pear or potato growers in the United States (Grieshop et al., 1988; Waller et al., 1998). This inconsistency can be explained in many ways. Firstly, small farm owners differ between countries and between agro-ecological zones (Bijman et al., 2007). For instance, in Europe most of the growers are small farm owners. They adopted commercial BCAs in IPM programs because of the rules and regulations and consumer demands, as well as the greenhouse farming system. Secondly, the adoption of IPM also depends on the contextual factors such as location and pest intensity. The present study could not rule out these two factors.

Interviewed citrus growers pointed out that Australia has different climates in different states and pest intensities were largely influenced by the climate. For instance, Queensland is further north than citrus growing regions of South Australia or New South Wales, and citrus growers were more likely to use *Aphytis* spp. in IPM to control red scales than the other states in Australia. The result is consistent with another study that found locational impacts such as climate, topography and isolation of the orchards and the available cost-effective pest management options have influenced the adoption of IPM in apple growers in Australia (Kaine and Bewsell, 2008). Finally, other studies found that landscape scale relates to biological control. For instance, a higher density and diversity of natural enemies tend to have lower pest pressures and crop damage in complex, highly connected farm landscapes with a high proportion of non-crop area than in simpler agriculturally dominated landscapes (Jonsson et al., 2008).

Users of commercial BCAs incurred crop losses of only 5%–10% per year, whereas non-users incurred 11%–15% losses per year. Perhaps users maintained an ecologically balanced cropping system that contains good numbers of natural enemies such as predators and parasitoids. As a result they produced better quality fruit and met the export market's requirements as well as those of domestic markets. Different markets have different pricing and require different quality and pesticide residue levels. Many countries have lower maximum pesticide residue limits than the Australian domestic market (Fitzpatrick, 2011). Users meet the export market pesticide requirements and can export more fruit. This makes greater profit than the same quality in the domestic market. The result is consistent with other studies which found that using commercial BCAs in IPM programs increased farmers income by increasing fruit production and yields or remained the same because phytotoxic effects of pesticides no longer occur (van Lenteren, 2000a; Moser et al., 2008). This study did not attempt a cost-benefit analysis of the adoption of commercial BCAs. This type of analysis reveals trade-offs between the benefit of commercial BCAs and their cost. This is one of the limitations of this study and merits further investigation.

In this study, interviewed citrus growers pointed out that combining commercial BCAs and insecticide applications make pest management expensive. Chlorpyrifos, an organophosphate (broad spectrum insecticide), is the most popular insecticide for pest control among the Australian citrus growers. However, commercial BCA users were more likely to use selective insecticides such as Movento and Spinosad.

Other researchers found that combining commercial BCA releases with insecticides may provide cost-effective and an adequate control. For instance, *P. persimilis* was cost-effective in controlling two-spotted spider mite in strawberries if combined with Abamectin applications. The two treatments combined produced the greatest net benefit rather than either of the treatments alone (Trumble and Morse, 1993). In addition, the breakeven cost of using commercial BCAs such as *P. persimilis* indicates its potential to improve grower profitability at current prices (Gardner et al., 2011). The citrus grower interviews were not consistent with these results but results from surveyed users showed consistencies. More users agreed that using commercial BCAs are cheaper and profitable but non-users disagreed or remained undecided with these statements. On the basis of these current results these inconsistencies can be explained in two ways.

Firstly, it was the perception of non-users that commercial BCAs are expensive. Most of them are small farm owners and they do not have the resources required to adopt successfully commercial BCAs. So when they calculated expenses for commercial BCAs and chemical pesticides, they may have included costs such as the labour for monitoring and releasing BCAs and consultant's fees. Other studies noted that commercial BCAs carry a higher cost than chemical pesticides in either direct costs or indirectly for the labour of monitoring and releasing (Moser et al., 2008). This is one of the economic barriers that deterred growers from using commercial BCAs.

Secondly, surveyed users were more likely to be large farm owners (more than 40 hectares of land under citrus) and have more resources that are required for the adoption of commercial BCAs. When they calculated expenses for commercial BCAs and chemical insecticides, perhaps they did not calculate the costs of other resources that they already have (the labour for monitoring and releasing BCAs and a consultant's fees). Further study is recommended to calculate the pest management expenses per hectare including all expenses.

Adoption of commercial BCAs is information-intensive, requiring extra expertise, or reliance on a consultant. Large farmers can more easily adopt commercial BCAs because they have those resources. The resource-poor non-users are mostly small farm owners and have limited resources. They could not perhaps afford to hire a consultant to adopt commercial BCAs. In this study, users had a wide variety of pest management decision makers such as owners, owner and consultant, owner and manager, manager and consultant and manager alone. In contrast, more non-users made their pest management decisions by themselves. The current result supports other studies which found that large farm owners offer managers or operators more flexibility in the decision making of pest management. They can try new technology more readily than small farm owners (Nowak, 1987; Tiwari et al., 2008). This shows that pest management decision making was influenced by economic factors which governs the adoption of commercial BCAs in IPM programs.

In terms of technological barriers, interviewed citrus growers pointed out that if they have to use an individual commercial BCA for an individual pest, then it makes it unrealistic and very expensive. In addition, they pointed out that *Aphytis* spp. is the only commercial BCA that is available to control red scales in citrus crops. For multiple pest problems, citrus growers were forced to use chemical insecticides not only in Australia but also in other countries as well. Very few of them are aware that other commercial BCAs are available for citrus pest management. *C. montrouzieri* is available to control mealy bugs and a generalist predator, *M. signata* is also available. The survey of California citrus growers noted that apart from *A. melinus,* other biological control agents are not commercially available. A variety of other commercial BCAs may not be the most effective means of enhancing biological control of other pests in California citrus orchards (Grogan and Goodhue, 2012). Perhaps, these technological barriers made commercial BCAs questionable and expensive. This is one of the technological barriers that influence the economic factors and limits commercial BCAs as an option when multiple pest species were present.

This result showed that *Aphytis* spp. is a widely used commercial BCA among users. Interviewed citrus growers and surveyed users were more likely to perceive that *Aphytis* spp. is effective and achieved very good control, whereas, in general non-users perceived that it is not effective. Few of the non-users had tried commercial BCAs but still perceived that chemicals are more effective than commercial BCAs. *Aphytis* spp. is a widely recognised effective parasitoid of red scales and its effectiveness is largely dependent on the dispersal and host-location behaviour of the wasps (Suverkropp et al., 2009; Tabone et al., 2012). The timing of pesticide applications and release of commercial BCAs are critical to effective control. These results showed that non-users do not fulfil these factors for successful use of *Aphytis* spp. They used broad-spectrum insecticides such as chlorpyrifos, kept the earth bare and perhaps were less likely to monitor pest development. As a result, they were more likely to perceive that *Aphytis* spp. is not effective which deterred the growers from adopting commercial BCAs.

In terms of farm practices, this result showed that the vast majority of citrus growers (users and non-users) use conservation biological control. Intercropping was not a common practice but most use cover crops perhaps grass or sometimes clover. Users were likely to use grasses as a cover crop to diversify the citrus orchards. This enhances the impact of endemic or native natural enemies and also of commercial BCAs such as *Aphytis* spp. For example, Kelly's citrus thrips (*Pezothrips kellyanus*) is a serious citrus fruit pest in Australia and causes estimated damage of some AUD$6 million a year (Davidson, 2001). Research found there was an association between the presence of dense, good-quality ground cover such as perennial grasses and an absence of damage by Kelly's citrus thrips. This reduction in damage was believed to be the presence of high densities of generalist predators. These growers are benefitting from conservation biological control (New, 2002; Colloff et al., 2013). Cover crops such as grasses also control dust problems (Ingels et al., 1994). In this study, perhaps non-users use grasses for dust control and other reasons. Users were more likely to avoid clovers as ground cover than non-users because many pests obtained benefit from clovers such as the lightbrown apple moth *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae) (Begum et al., 2006). In this study users achieved more revenue than non-users. Perhaps conservation biological control has an impact on this achievement.

This study also showed that organic growers do not use commercial BCAs. A few non-users used conservation biological control and grasses as cover crops. Perhaps, they produced their crops organically or used microbial biological control agents but this study did not consider these biological control agents. As they are not considered as 'commercial BCAs' the respondents are considered as non-users. According to the International Federation of Organic Agriculture Movement (IFOAM), insect pest problems may be controlled through an augmentation or introduction of predators and parasitioids with the combination of other practices. Perhaps, their ecologically managed systems lead to a higher natural enemy diversity and abundance. With the combination of other practices, commercial BCAs were made less effective (Zehnder et al., 2007), which deterred growers from using commercial BCAs. This merits further research especially for the Australian insectary industry because this is a window of opportunity for them to further expand.

Australian citrus growers are likely to reduce the use of chemical insecticides. Surveyed growers rotate their insecticide use and apply only when the pest risk is higher than acceptable. They are aware of the insecticide's impact on beneficial insects. A study found that the biological control of Kelly's citrus thrips was disrupted and emerged as a major pest because overspill from the foliar application of organophosphate insecticide sprays destroyed the soil-dwelling predators (Baker et al., 2011).

Growers were concerned about insecticide impacts on health and the environment. One of the interviewed citrus growers switched to IPM because the previous owner became sick. In addition, the growers think that chemicals pollute the environment. They think that if chemical use occurs for long periods the effect on the environment will be not sustainable.

Interviewed growers and surveyed non-users were likely to perceive that growers are willing to switch to biological control if a suite of biological control agents were available for all the pests, commercial BCAs became cheaper, consumers accept blemished fruits, retailers put pressure on growers and government introduced laws to use biological control. One of the important reasons for switching to biological control is that 'consumers accept blemished fruits'. The Sydney Morning Herald in goodfood.com.au recommends each week fruit and vegetables that are 'good value' at low prices. Blemished oranges are given as a 'good buy' at reduced prices, but there is no indication of growth conditions. Retailers give no information on whether the fruit is grown with minimal pesticides.

The present study measured citrus growers' attitudes or perceptions of the main driving factors towards the use of commercial BCAs. Users generally agreed with the positive attributes about commercial BCAs. This agreement unfolded the driving factors for the implementation of commercial BCAs. This result is consistent with another study which noted that positive attributes of commercial BCAs increases growers confidence in commercial BCAs (Moser et al., 2008). In this study, citrus growers disagreed with two potential driving factors for commercial BCAs adoption. These were, 'pest insects develop resistance to insecticides' and 'hazardous insecticide withdrawal from the pest control market by the government'. These two factors are recognised worldwide as driving factors for commercial BCAs adoption (Trumble, 1998; van Lenteren and Bueno, 2003; Cock et al., 2010; Pilkington et al., 2010). Historically, in the citrus crop, red scale (*A. aurantii)* developed resistance to Methidathion, (an organophosphate insecticide) in the 1990s and this was first reported from Australia (Collins et al., 1994). Since then Australia has developed one of the most successful IPM programs for citrus pests. Additional serious pests have arisen progressively such as citrus leafhopper (*Empoasca smithi*), citrophilous mealybug (*Pseudococcus calceolariae*) and Kelly's citrus thrips (*Pezothrips kellyanus*). To control these pests, currently organophosphate (mainly chlorpyrifos) remains the prime control method. This results showed that chlorpyrifos was widely used among the citrus growers, but it has been used carefully and not as a routine insecticide. Thus they have not faced a resistance problem. In contrast, in the 1980s, many populations of citrus thrips became resistant to organophosphate and carbamate insecticides in the San Joaquin Valley, California (Morse and Brawner, 1986; Grafton-Cardwell et al., 2001).

In terms of information, citrus growers use a wide range of sources about the topic of pest management such as workshops, field days, pamphlets, other farmers, insectary companies, internet, citrus news, consultants and The Good Bug Book. There was little variation apparent between users (large farm owners) and non-users (small farm owners). In Europe, previous studies found that growers' sources of information were extension agents, agricultural journals (local or national), TV, radio and internet regarding commercial BCAs (Moser et al., 2008). Interestingly, in this study in Australia, citrus growers did not report TV or radio as sources of information regarding commercial BCAs. Many studies noted that technology information is an important factor which influences growers' outlooks and expectations towards the resource problems and technology choices (Place and Dewees, 1999; Pretty and Uphoff, 2002; Doss, 2003; Lee, 2005). In these studies, information uptake was influenced by different factors such as social class and farm size (Jackson et al., 2006). Large and small farm owners did not vary in their sources of information. However, the information regarding technology varied with different sources. Increased information or good quality information does not necessarily lead to adoption. It may influence growers' initial decision to adopt or not to adopt or abandon previously adopted technologies (Lee, 2005). Perhaps this area warrants further research to promote a larger scale uptake of commercial BCAs by the Australian growers.

This study investigates the government or other organisational help to the implementation of commercial BCAs for pest control in citrus crops. The results showed that South Australian interviewed citrus growers note that no government extension officers exist anymore. Both interviewed and surveyed citrus growers pointed out that they do not receive any financial support from the government except information. They have received consultancy services from the insectary industry, agricultural chemical companies and other organisations. Growers appear to be unaware that Horticulture Innovation Australia Ltd. received funding from the Federal government in addition to the money from grower levies to put towards research, but not for extension services. In this respect, other researchers found that over the last two decades Australian extension practices have declined in public funding from traditional one-on-one extension to a rise in group-based extension. In many situations, this has the potential to create a far more complex social interaction between group facilitators and landholders (Pannell et al., 2006). Perhaps this has been influenced by the adoption of commercial BCAs. In many European countries, the government plays an important role in fostering the use of commercial BCAs. In Israel the government partially subsidised the packaging of BCAs and offered free technical support at the beginning of the program (Moser et al., 2008). Many studies noted that indirect assistance gave better results than direct assistance such as subsidises (Allen et al., 2002; Moser et al., 2008). The Australian government gives indirect assistance to incorporate the commercial BCAs into IPM programs by funding different research projects.

6.5 Conclusions

The adoption of commercial BCAs depends on a range of factors. Economic factors have a major impact on their adoption by citrus growers. Large farm owners were more likely to incorporate commercial BCAs into their IPM program and received better profit than small farm owners. Some technological barriers influenced the adoption. Growers beleived that it is complicated, managing a multiple pest complex, and using chemicals with commercial BCAs. In addition, commercial BCAs are not used by organic growers. Growers ruled out insecticide resistance and insecticide withdrawal as driving factors for the adoption of commercial BCAs. Growers did not receive any support from the government except information. Growers are willing to incorporate commercial BCAs into their pest management if it fulfilled certain conditions.

This result raises the prospect of the commercial BCAs producer focusing on non-users to increase their adoption. The question remains as to whether insectary companies will be successful in convincing these non-users. Non-users have perceptions about the difficulty of adoption of commercial BCAs that are not realistic. Perhaps insectary companies can change non-users views through education and technical support. In this area further research is necessary perhaps Participatory Action Research. This study identified that it is necessary to analyse costs and benefits and this should be done before and after the adoption of commercial BCAs. Several other areas have been identified as of potential interest for further research to a better understanding of adoption of commercial BCAs.

Chapter 7: General discussion

This study focused on the Australian commercial insectary industry. This industry commercially produces biological control agents (predators, parasitoids and nematodes of invertebrate pests) which are the agents for augmentative biological control. Augmentative biological control in Australia is being hindered by a range of factors and as a consequence the Australian commercial insectary industry is not expanding to the same extent as in other countries. These factors were identified by insectary owners (industry participants), researchers (who are doing research on citrus pest management) and citrus growers, and uncovered the fundamental barriers and drivers of this industry. This chapter synthesises and discusses the broader implications of the results presented in Chapters 4, 5 and 6 (Objectives 1, 2 and 3) to the overall aim of this project.

The Australian commercial insectary industry started with citrus pest management. To follow the trend of the world's first insectary in the USA (1950), the first two Australian insectaries were established to reduce the insecticide cost in citrus pest management. Perhaps after World War II, growers had a difficult economic situation and wanted to reduce the pesticide cost and were looking for alternatives such as biological control. As a result insectary establishment was initiated in Australia (in 1971 and 1981) as well as around the world (Furness et al., 1983; Papacek and Smith, 1992).

Over the past 40 years the Australian industry has expanded from one company to five in 2014 (Chapter 4). The reduction in number from seven (in 2011) to five was because two small companies merged with two large companies in different states. In Europe, the use of commercial BCAs in greenhouses began to reduce the use of pesticides (Hajek, 2004).

The Australian insectary industry was started in 1971 but currently it is far behind the European insectary industry that was founded in 1968.

Historically, economics, insecticide resistance and pesticide reduction were the driving factors that initiated the insectary industry. Perhaps pesticide reduction was the major factor that drove today's European insectary industry. In Australia, the growth of this industry became static after the initial (1991–2001) expansion. Recently this industry has further expanded (2011–2014) its product lines due to the insecticide resistance of two major pest insects. Insecticide withdrawal has also influenced the expansion of this industry. Interviewed insectary owners, researchers and many other researchers identified these factors that enhance the expansion of the insectary industry around the world (Trumble, 1998; van Lenteren and Bueno, 2003; Warner and Getz, 2008; Pilkington et al., 2010; Cock et al., 2010; van Lenteren, 2012). In this study, citrus growers ruled out these factors because they did not see the historical point of view, they just considered their own situation. Perhaps, from the history of this industry establishment and expansion, the Australian insectary owners will get future direction for the expansion of their insectary companies.

Currently (2014), five Australian insectary companies are operating commercially and mainly serve the horticulture industry. The European industry is the largest industry in the world and produces 175 species of commercial BCAs to control many pests in many cropping systems (van Lenteren, 2012). Compared with European and American industries the Australian insectary industry is very small in many aspects such as gross sales and employment.

The Australian insectary industry is a very small economic sector and has estimated gross sales well below AUD$10 million for the 2010–2011 financial year. According to the Australian Pesticides and Veterinary Medicines Authority (APVMA) the insecticide market was AUD$363.7 million (US$393.4 million) for the 2010–2011 financial year. The Australian commercial BCAs market constituted less than 3% of the Australian insecticide market. The global commercial natural enemies market for greenhouses were estimated at about 150–200 million Euros (about US$167–223 million) in 2008 and the most important markets are in Europe (75% of the market value), followed by North America (10%) (Cock et al., 2010).

In terms of employment, only two Australian companies are relatively large (employing more than ten people). Out of the 30 world's largest commercial insectary companies, 20 are located in Europe and one of the largest companies employed more than 600 people in 2011. In North America 22 insectary companies employed a total of approximately 200 employees (Warner and Getz, 2008).

Many factors are involved in the lack of growth of the Australian industry. The factors are discussed below:

The cost of a new insectary establishment as well as the established insectary is one of the major barriers in Australia. There were not sufficient sales at least in the first year to cover all the expenses. Currently most of them were facing challenges to expand their infrastructure which was needed for their business expansion. Interviewed researchers also pointed out the need to produce cost-effective products but it was a small operation and could not produce them. Often an unexpected operating cost (e.g., contamination of the host insect population) posed a greater threat to a new insectary and the economic viability of an established insectary as well (Warner and Getz, 2008). This study was consistent with other studies that identified that the barriers to maintaining the host populations (insects or plants) are more expensive and challenging than rearing the actual commercial BCAs (Penn, 1998; Warner and Getz, 2008). In addition, many species are used seasonally, especially for outdoor crops, but producers have to maintain that species year round (Hale and Elliott, 2003). The rearing system also needed a controlled environment which required an extra cost. Perhaps, there is an opportunity available for this industry to produce multiple commercial BCAs from a single host and thus reduce the production costs.

This study revealed that bringing a new commercial BCA into the market is one of the major barriers to this industry. Previously, perhaps this industry followed a single-target approach but recent examples provide evidence that this industry can overcome most of these barriers through a multi-target approach. This means finding a single commercial BCA that controls a pest that damage multiple crops or a commercial BCA that controls multiple pests. This multi-target approach helps to bring different industries together. *Eretmocerus hayati* Zolnerowich and Rose (Hymenoptera: Aphelinidae), is a parasitoid of the Silverleaf whitefly which is a key pest in different crops (such as cotton, fruit and vegetables) in Australia. This pest developed resistance to multiple insecticides. No effective parasitoids were available in Australia because this pest was introduced recently (1992–1993). Collaborative research with insectaries, government and other industries brought this parasitoid (*E. hayati*) from Texas to Australia for evaluation as a biological control agent (Goolsby et al., 2005; DeBarro and Coombs, 2009). The insectary industry saw opportunities with this biological control agent in glasshouses as well as broad acre cropping systems and moved to exploit this new market. Currently this commercial BCA is commercially available in the Australian market (DeBarro and Coombs, 2009; Bugs for

Bugs, 2015). A similar type of collaborative research has been undertaken on fruit spotting bug management in different crops (different fruit and nuts). One of the effective broad-spectrum insecticides, Endosulfan, used against the bug, has been deregistered globally. As a result a parasitoid, *Anastatus* spp. (Hymenoptera: Eupelmidae) of fruit spotting bugs, *Amblypelta* spp. (Hemiptera: Coreidae) is currently under development in Australia (Huwer et al., 2011).

This discussion indicates that collaboration is essential to bring a new commercial BCA into the pest control market. Collaboration is also essential within this industry such as sharing information and marketing. This industry can even collaborate with overseas insectaries such as the European insectary industry. A study on the North American insectary industry found that insectary owners believed that the European scientific communities can provide basic and applied research support which is essential for the insectary industry expansion (Warner and Getz, 2008). Another option may be merging insectaries which may help to broaden product lines and the customer base. Recently two Australian insectaries were merged with two larger insectary companies that help them to increase product lines and the customer base because these insectaries were situated in different states. This type of collaboration and merging will help this industry expand.

Collaboration is also essential for the successful implementation of commercial BCAs. The commercial BCAs are applied in a system which needs to be favourable for them to make them effective. Other studies found that a multi-disciplinary approach is necessary for the successful implementation of commercial BCAs (Ehler, 1991). Therefore, collaboration is crucial at the industry level and in the adoption of commercial BCAs as well. Collaboration is also essential with the pest management consultancy organisations or other distributing companies that have enough technical support staff to market commercial BCAs because growers, especially small farm owners, need technical support. Perhaps a group of growers can hire a consultant to implement the commercial BCAs into their pest management program.

Market size is one of the major factors that hindered the growth of the Australian insectary industry. Most of the European companies export their products around the world. A large number of greenhouse cropping systems are found in Europe and in the greenhouse cropping system pest populations increase very quickly. Pest insects reproduce faster under this favourable environment. This demands more frequent insecticide applications. As a result pests developed resistance to insecticides very quickly and growers looked for alternatives such as IPM and commercial BCAs (van Lenteren and Woets, 1988; van Lenteren, 2000a). In addition, most of the greenhouses are located in urbanised areas. As a result the use of pesticides is restricted (van Lenteren et al., 1997; Warner and Getz, 2008). The opposite situation exists in the Australian insectary industry.

Previously this industry exported commercial BCAs in several countries. Interviewed insectary owners and researchers both pointed out that biosecurity is a huge issue for export and import of commercial BCAs in Australia as well as overseas. In this regard interviewed researchers and other researchers pointed out that most of the pests were introduced in Australia (New, 2002). Often no natural enemies are available for a particular pest so it is necessary to import natural enemies from overseas for successful pest management. This is one of the barriers for this industry's growth. In many other countries, insectaries face the same barriers for the international movement of commercial BCAs (Warner and Getz, 2008). Biosecurity is not only a problem for the international market but also creates problems for the domestic market as well. Often interstate biosecurity creates problems for rearing host materials as soil and plant movement is restricted between different states. The interstate barrier for the Queensland fruit fly was a serious impediment for this industry. Interviewed citrus growers pointed out that it created major conflict and likely to have negative influence on the adoption of commercial BCAs. Recently the states of NSW and Victoria have abandoned the fruit fly exclusion zone at their border because of repeated infestation and the loss of key insecticides through deregistration. Instead they have tried to develop a long term management strategy for Queensland fruit flies (NSW Department of Primary Industries, 2012). South Australia continues to maintain fruit fly exclusion and use Sterile Insect Techniques (SIT) to eradicate fruit flies (Primary Industries and Regions SA, 2015). This will help the Australian insectary industry overcome the domestic biosecurity barriers. As well their clients (growers) might not be forced to use chemical pesticides. Many countries such as Mexico use mass reared parasitoids (*Diachasmimorpha longicaudata* (Ashmead) (Hymenoptera: Braconidae) to control Mexican fruit fly *Anastrepha ludens* (Loew) (Diptera: Tephritidae) (Cancino and Montoya, 2006). Similar type of mass rearing method of two species of Queensland fruit flies' larval parasitoids, *Diachasmimorpha kraussii* and *D. tryoni* is underway in Australia (Agriculture Today, 2010). These biological control agents will help this industry to further expand.

Another reason may be supply chain or logistic problems. Any delays can result in degradation of insect quality (Warner and Getz, 2008). In the Australian market logistics is not only a barrier for the export market but for the domestic market as well. All insectaries were established in the rural areas in Australia and the question may arise why the insectaries were established there? This study reveals that major cities are expensive. Secondly, customers are based in the rural areas as well. For the success of the business they should be nearby to the customers. Perhaps they did not consider customers outside these areas. As a result the industry remained hidden as reported by interviewed researchers (Chapter 5). Many European insectaries established their production facilities in different countries to overcome these barriers (Warner and Getz, 2008). There were no such types of overseas production facilities established by the Australian insectary companies.

In Australia, the broad acre cropping system is the biggest system. Currently the protected cropping system is expanding rapidly especially in the tomato industry for the hydroponic cropping system (Taig, 2009). Perhaps this will drive the Australian insectary industry for future expansion. In Europe, the major parts of commercial BCAs are used in greenhouses but in the USA, most of the commercial BCAs were sold for application in open field crops (van Lenteren et al., 1997; van Lenteren and Bueno, 2003; Warner and Getz, 2008). Australia followed the USA trend and perhaps this may be one of the barriers for the industry expansion. In addition, European protected cropping systems use bumble bees as pollinators whereas mechanical pollinators are used in Australia. This may be another driver in European insectary industry expansion due to the low tolerance of bumblebees to pesticides. Greenhouse growers are required to adopt IPM strategies involving the use of commercial BCAs.

The Australian insectary industry has not yet penetrated into the Australian organic cropping system. The retail value of the ‘organic market’ in Australia was estimated at least AUD$1 billion in 2010 with annual growth projections ranging from 10% to 25% for the years ahead (Monk, 2012). This market is one of the windows of opportunity for the Australian insectary industry expansion. Many researchers, and the national and international guidelines, recommended the use of parasitoid and predator commercial BCAs for pest management in organic farms (Horne, 2007; Zehnder et al., 2007; Neeson, 2007; Madge, 2009). Some researchers found obstacles such as organically registered pesticides that may cause the commercial BCAs to be less effective within the organic cropping systems (Speiser et al., 2004; Thakore, 2006; Zehnder et al., 2007; Vanaclocha et al., 2013). Other studies found that most organic growers rely primarily on conservation biological control techniques. As a result they manage the whole system which leads to higher natural enemy diversity or use biopesticides that are particularly registered for the organic cropping system (Furlong et al., 2004; Warner and Getz, 2008; Macfadyen et al., 2009). In addition, organic food consumers have different attitudes from the other consumers because they accept blemishes on fruit and vegetables at a certain level. As a result, organic growers get higher premiums, and perhaps they accept a higher level of crop damage (Monk, 2012).

The lack of growth of the Australian insectary industry depends on the growers' adoption of commercial BCAs. A wide range of factors has impact on their decision. To implement commercial BCAs it is necessary to implement IPM because commercial BCAs are always used within an IPM program. There were many factors that influenced growers to adopt commercial BCAs.

The survey results revealed that economics is one of the major factors that influence growers' adoption of commercial BCAs (Chapter 6). Farm size is one of the economic factors that strongly influence the commercial BCAs user and non-user growers. Non-user citrus growers believed that using commercial BCAs required some resources such as knowledge and time. Large farm owners meet these requirements and were more likely to apply commercial BCAs into their pest management programs. This is consistent with other results that large farm owners were more likely to adopt a new technology (Feder et al., 1985; Fernandez-Cornejo, 1996; Shennan et al., 2001; Grogan and Goodhue, 2012;

Akudugu et al., 2012). Interviewed insectary owners indicated that their volume of production was increasing because growers increased their farm size which indicates that farm size has a large impact on the expansion of this insectary industry.

Small farm owners differ among different countries (Bijman et al., 2007). For instance, in Europe most of the growers were small farm owners but they were influenced by several other factors such as legislation, greenhouses, and consumers. Basically, commercial BCAs are not expensive but monitoring and the releasing process make it expensive (Moser et al., 2008). If this insectary industry wants to attract these small farm owners then they needed to give them technical support. Perhaps this is one of the major factors that hindered the growth of this industry because this industry is horticulture based. Most of the horticultural growers are small farm owners in Australia. This result showed that the insectary industry serves mostly large farm owners and expanding their business is based on this small group of large farm owners.

Technological barriers are other factors that deterred growers from adopting commercial BCAs. Often this industry offers a single commercial BCA for a particular cropping system whereas interview and survey results showed that citrus growers faced multiple pest problems (Chapter 6). Then growers do not have any choice other than some insecticide application. There were many other technological barriers that created problems.

Regional effects or climatic conditions have a major influence on the growers' adoption of commercial BCAs. Interviewed researchers and citrus growers reported that often one major pest in one region became a minor pest in another region or in different climatic conditions. Other studies found that climate is perhaps the most important factor that influenced insects' physiological development, migration and dispersal (Risch, 1987; Selvaraj et al., 2013). Similarly, the availability and activities of natural biological control agents depends on different regions and climatic conditions. For example *Aphytis melinus* is extensively distributed in the citrus districts of Victoria, South Australia, Western Australia and inland New South Wales and in Alice Springs in the Northern Territory (Smith et al., 1997). *Aphytis lingnanensis* is an effective parasitoid of red scale in Queensland and perhaps in northern New South Wales as well (Papacek and Smith, 1992). To implement commercial BCAs, insectary owners and researchers must be aware of the entire pest complex, their interactions with other insects and organisms in a crop and climatic factors, but often researchers have focused on a single pest (Olsen et al., 2003; Horne et al., 2008). Basically, this result indicates that insectary owners and researchers are required to consider a holistic approach to the implementation of commercial BCAs as a pest management tool.

The surveyed results showed that the adoption of commercial BCAs required more knowledge and training. Several options may be available for the insectary companies to support growers. One option may be that products are supplied through consultants or distributing companies that have enough technical support staff. This study revealed that a few of the insectary companies supply commercial BCAs through consultants and this also broadens the customer base. Other researchers pointed out that conflict of interest may arise if distributors sell chemical pesticides as well. Often growers take commercial BCAs from different insectary companies because one insectary may be unable to provide all the required commercial BCAs. In that case, the insectary company faces challenges to implement successful biological control (Valentin, 2003). Insectary owners need to be strategic and consider all available options.

Initially, all the Australian insectary companies gave consultancy services and perhaps that was one of the reasons to expand the companies at a certain level. The Australian insectary owners sell their products direct to the customers. In other countries such as in North America, growers buy commercial BCAs from retail outlets, which perhaps give consultancy services as well (Warner and Getz, 2008). In Europe, most of the insectaries gave consultancy services to the growers. This type of service is essential for this business because this business is specialised and knowledge intensive.

Growers' attitudes play an important role in the adoption of commercial BCAs. This study pointed out that some growers have different attitudes towards the commercial BCAs. Many researchers reported that any change is stressful which significantly influence the growers' decision making process (Feder et al., 1985; Pannell et al., 2006; Horne et al., 2008). The survey results showed that most of the commercial BCA non-user citrus growers were not confident with commercial BCAs. On the other hand they perceived chemical pesticides to be effective (Chapter 6).

Growers are largely influenced by pest management consultants and extension agents. Many insectary owners realise that the implementation of commercial BCAs requires an alternative approach or extension education. Often extension agents undercut growers' confidence on commercial BCAs around the world (Warner, 2007; Warner and Getz, 2008). This study shows that extension agents required education about commercial BCAs because they are the agents to change growers' attitudes (Chapters 4 and 5). In Australia, historically agricultural extension services have been provided by State Departments of Agriculture. This has been substantially changed and varies from state-to-state. South Australia and Western Australia have almost no staff, NSW, Victoria and Queensland have significant extension capacity but these states also focused on farmer groups rather than one-to-one extension services (Marsh and Pannell, 2000; Rose, 2005). Many researchers pointed out that failure to adopt IPM or commercial BCAs is largely dependent on extension services (Malone et al., 2004; Kaine and Bewsell, 2008).

In addition, interviewed researchers noted that during the last two decades the citrus industry as well as other horticulture industries has become export oriented. Often to meet the export market requirements they use chemical based pest management or an IPM program. The export market requirements were different and influenced this industry in both a positive way, such as the European market may need lower pesticide residues, and a negative way, such as some USA and Asian markets may require blemish free fresh produce. In that case, growers have to use chemical pesticides to produce cosmetically perfect fruit and vegetables.

Consumers' awareness is very important because the consumer can create market pull that changes the growers' thinking about the use of pesticides (Pilkington et al., 2010; van Lenteren, 2012). Other studies found that organic food consumers' attitudes are different from other consumers. They are motivated by a range of benefits from eating organic foods such as chemical free, additive free, environmentally-friendly, and no genetically modified organisms (Monk, 2012). This study pointed out that similar type of motivation is required for the IPM produced fruit and vegetables but it was also revealed that supermarkets and horticultural industries were reluctant to promote IPM produced fruit and vegetables. For consumer education the insectary companies can establish IPM shops or contact local shops that sell fresh produce only. They can encourage these shop owners to sell IPM produced fruit and vegetables and play videos that will show how these products are grown. Even in the major cities that type of shop can sell IPM produced fruit and vegetables. Even in big supermarkets like Coles and Woolworths this can be done. Perhaps this will increase consumers' awareness about IPM.

Many countries have withdrawn hazardous pesticides or levy pesticide taxes or reduced the registration fees for biopesticides to promote commercial BCAs (Cannell, 2007; Pilkington et al., 2010; van Lenteren, 2012). For example, in 2009 the European Union adopted IPM legislation to achieve sustainable use of pesticides, and priorities non-chemical methods (Schellhorn et al., 2013). In addition, the European growers get direct financial support from the government as well (Moser et al., 2008; Geiger et al., 2010). This study suggested such types of legislation are needed in Australia to promote commercial BCAs and enhance this industry's expansion.

Direct market competition exists in the Australian insectary industry, which may be another barrier for the expansion of this industry. One company (direct competitor) offers the same products (that produced by the other company) to the same market and customer base and created direct market competition within this industry (Oman, 2011). This direct competition might be creating price competition and commercial BCA's quality degradation. This study revealed that insectary owners were very concerned about direct competitors. They were cautious to hire and train people or keep secret their rearing information because it will be risky for their business. Other researchers described how the insectary companies have little protection except to keep secret their production and not to facilitate competition (Cock et al., 2010). Pesticide research and development is protected by the international laws that give the security of the intellectual properties to the chemical companies that develop a new chemical pesticide (Javier et al., 2010). There is no registration or patents in the domain of the Australian insectary industry except for nematodes which are patent protected. The Australian insectary owners believed that the patenting process is expensive and required certain levels of experience and time. Most of the countries, such as the European countries and the USA, have patent protection for commercial BCAs (Bera, 2009; Javier et al., 2010). As a result, perhaps they can expand their business. One of the European companies runs their business in several countries and markets in 45 different countries and employed more than 600 people in 2011 (Warner and Getz, 2008; van Lenteren, 2012).

In Australia, most of the companies are poorly capitalised and occupied a niche market. The lack of patents makes this industry a risky business and constrains the commercialisation and integration of commercial BCAs into crop protection. Perhaps this is one of the reasons different funding bodies reduced their investment in this industry research. The patent process can bring new and improved commercial BCAs into this market or the large insectary companies perhaps can give or sell licenses to the secondary insectary companies and expand their business (Javier et al., 2010).

The insectary owners have hands on experience and a lot of data but never publish it in a scientific journal. Perhaps they were not interested, or wanted to maintain business secrecy, or do not have time to publish. Often insectary companies were unsuccessful in commercially developing a new biological control agent and this information remains unpublished. If this information is published then perhaps this information may be helpful for the future development of a new commercial BCA. The augmentative biological control research area will also be richer for this information. A new insectary owner with no published knowledge to rely on needs to start afresh, which involves large amounts of money and time. Perhaps this information secrecy or not publishing may be one of the important impediments for the expansion of this industry.

As one-person operated businesses the Australian insectary owners are very happy because they are economically viable, and reached certain levels of expansion. They do not want to expand further and a few of them reported that they do not have the infrastructure to produce and serve a larger number of consumers. Perhaps protectiveness or business secrecy is one of the main barriers for this industry expansion. As mentioned before the insectary owners are concerned about competitors. Conversely, if they train more people for technical support to growers and for rearing systems then they can expand their business. Firstly they can produce cost-effective products and attract more growers especially small farm owners. The adoption of commercial BCAs is information-intensive and required a consultant for technical support. As a result this industry could not penetrate the vast majority of the Australian horticulture growers. If these companies can attract these small farm owners then this industry will expand rapidly and change the whole scenario. Secondly, these companies will be able to establish rearing facilities in different states, even overseas and overcome biosecurity and logistics barriers. This industry will be able to invest more money for researching quality issues of commercial BCAs or to develop a new commercial BCA. They can promote commercial BCAs and this will create a bigger market. As a result this industry will be expanded. The insectary companies need to patent their products (rearing information and pest control techniques because free living organisms cannot be patented) in order to encourage the expansion.

According to the results obtained in this study several areas needed further research. More research is needed on technological complexities. Limited research has been done on why organic growers do not use commercial BCAs, so this area warrants further investigation. Some social research on growers and consumer attitudes will help to implement commercial BCAs and enhance the expansion of the Australian commercial insectary industry.

Chapter 8: Stakeholder feedback, recommendations and overall conclusions

Using multiple strategies or methods in Participatory Action Research (PAR) gathers the different perspectives of participants who are involved and increases the rigor and trustworthiness of PAR projects (Lennie, 2006). This research has a PAR framework and completed early interventions but did not complete the successive cycles because of time constraints and funding (see Chapter 3). This chapter further explores the views of these three groups (Australian insectary owners, citrus pest management researchers and citrus growers) totalling 27 of the sample population, all of whom had been previously interviewed. Accordingly, a summary report with preliminary results from the specific Objectives 1, 2 and 3 was sent to the interviewees and comments on the summary were canvassed. This feedback is incorporated into the final results and thus enhances the trustworthiness of the results (Lennie, 2006). The feedback helped to understand how interrelated variables affected one another and together developed the joint construction of the critical components of the commercial BCA adoption system. On the basis of the final results, recommendations and overall conclusions were developed.

This chapter addresses the specific Objective 4 (Chapter 1 and 3, Figure 3.2):

> Integrate Objectives 1, 2 and 3 to determine the economic, social and political factors that impact on the Australian commercial insectary industry and identify opportunities for this industry and public policy to create the environment to assist the industry.

8.1 Introduction

Participatory research approaches are a powerful methodology for increasing the relevance and effectiveness of research (Bruges and Smith, 2008). This methodology also ensured that knowledge and resources better addressed local issues when researchers and growers worked together (Taylor, 2013). Participatory research also helps to develop better recommendations by making better use of participants' knowledge (Pannell et al., 2006). Participatory approaches are flexible multiple strategies which increase the rigour and trustworthiness of the research are recommended (Lennie, 2006; Carter, 2008). Many studies have shown that the use of multiple data sources and collection techniques to study a single question, called 'triangulation', increases the trustworthiness of the research results (Staley and Shockley-Zalabak, 1989; Lennie, 2006). This research focuses on a particular industry, 'the Australian insectary industry'. An interview and questionnaire survey was conducted with the insectary owners, citrus pest management researchers and citrus growers to understand this industry, how it is operating, its growth, what problems it currently faces and what needs to be done for further development of this industry. A summary report was sent to the interviewees (who had been previously interviewed) for further input into the development of recommendations. This process is consistent with the PAR.

8.2 Methods

The key findings from the specific Objectives 1–3 (Chapters 4–6) were analysed, synthesised and discussed in Chapter 7. From this analysis and synthesis, a summary report was written which was used as a research tool to collect further comments and recommendations from the Australian insectary owners (9), citrus pest management researchers (9) and citrus growers (9). This report and cover letter was sent to the 27 participants by email on 26 July 2015 (Appendix 6). The report is in Box 8.1.

Box 8.1: A summary results report that was used as stakeholder feedback collection tool.

A comprehensive study of the Australian commercial insectary industry and its implications for augmentative biological control

Mahmuda Begum*, Peter Ampt and Sarah Mansfield

Faculty of Agriculture and Environment, The University of Sydney, NSW 2006 Australia.
* Corresponding author, Telephone: +61 2 86271064; Fax: +61 2 86271099;
Email Address: mahmuda.begum@sydney.edu.au

The Australian commercial insectary industry produces biological control agents (predator, parasitoid and nematode BCAs) to control pests. The adoption of commercial biological control agents (commercial BCAs) by growers is hindered by multiple factors. As a consequence the Australian insectary industry is not expanding to the same extent as in other countries.

The purpose of this study was to address the lack of growth of this industry and develop recommendations that will encourage industry expansion. During 2011–2013, interviews (27) were conducted to identify the perspectives of insectary owners, citrus pest management researchers and citrus growers. A national survey of citrus growers was also conducted during 2012–2013.

The Australian insectary industry started with citrus pest management in the 1970s. Over 40 years the industry has expanded from one company and one commercial BCA to five companies and 36 commercial BCAs in 2014. This expansion was largely in response to one pest (two-spotted spider mite) developing resistance to multiple insecticides in Australia. After this initial (1991–2001) expansion the industry has stopped growing.

Currently, two insectaries produce most of the commercial BCAs and most insectaries have produced just one species for the past 10–20 years. Most of the companies are poorly capitalised and occupy a niche market that has estimated gross sales well below AUD$10 million for the 2010–2011 financial year.

The size of the domestic market for commercial BCAs is very small and there is no export market. The industry is primarily horticulture based in Australia. Only a few organic growers use commercial BCAs.

Users of commercial BCAs have larger farms, more employees and achieved higher crop values per year than non-users. Users also usually work with a consultant. The complexity of the adoption of commercial BCA is the main reason that deterred small farm owners.

The insectary owners were very cautious to keep secret their rearing methods or other information because of commercial confidentiality. They were also cautious about training people. This constrained commercialisation and integration of commercial BCAs into crop protection.

It is clear that this industry faces many barriers. These are:

a) The cost of establishing a new insectary is very high.

b) To develop a new commercial BCA requires a large amount of money and research but this industry by itself does not have the resources.

c) Logistics created problems because any delays in transit might damage the commercial BCA's quality significantly. The industry is dependent on long distance transport because the industry and its clients are both based in rural areas and Australia is a large country.

d) Interstate biosecurity is one the barriers to industry expansion, especially the movement of soil and plant materials. Biosecurity is also an issue for export and import of commercial BCAs in Australia.

e) Adoption of commercial BCAs is information intensive and needs intense monitoring. As a result non-users, who are usually small farm owners and represent a large proportion of the citrus industry, are less likely to adopt commercial BCAs.

f) Commercial confidentiality creates a major barrier to industry expansion because there is direct competition between companies producing commercial BCAs.

g) In Australia, only nematode commercial BCAs are patent protected but the lack of patents for the remaining commercial BCAs makes this industry an unprotected business. The commercial BCA rearing methods and other associated technologies for their use may be the main subjects for patent because free living, naturally evolved organisms cannot be patented. In this regard, interviewed insectary owners perceived that the patenting process is expensive and requires a certain level of experience and time.

Interviewed insectary owners and researchers made some recommendations and the survey results agreed with some of their recommendations. This study recommends that:

1. Patents are essential for expansion of the Australian insectary industry. The Australian insectary owners need to change their attitude towards the patent system, like the American and the European insectary owners. Otherwise it will not be possible for the Australian insectary owners to expand their business as well as expand the industry as a whole.

2. The Australian insectary owners need collaboration with other research organisations. Collaboration is also essential between the industries (different crops) and within this industry (for marketing and sharing information).

3. The Australian insectary owners need a multi-target approach to develop a new commercial BCA which controls a key pest of multiple crops or controls multiple key pests. This approach also reduces the production costs by use of one rearing host (such as host insects, soil, plants, fruits, vegetables, or other natural and artificial diets) for production of multiple commercial BCAs.

4. Growers (especially small farm owners) need technical support to incorporate commercial BCAs into their pest management program. Perhaps the industry can develop technical support software for growers such as phone apps.

5. More species of commercial BCAs are necessary to manage all of the pests in a particular crop, for instance, citrus crops.

6. Very few organic growers use commercial BCAs. The insectary industry needs to focus on organic farmers and encourage their uptake of the right commercial BCAs.

7. The Australasian Biological Control Association Inc. needs to join with other related associations to form a lobby group to convince government to support this industry. Initiatives such as wider education about IPM and the introduction of an IPM logo for fresh produce to promote fresh produce grown using IPM are possible. Pest management consultants, extension officers and growers will benefit from such as a lobby group.

Therefore, the Australian insectary owners, policy makers, IPM researchers and practitioners need to take these recommendations into consideration to expand this industry. Several areas warrant further research to better understand adoption of commercial BCAs and how to support expansion of this industry.

The first reminder email was sent to the interviewees on 4 August 2015 and the second reminder email sent on 12 August 2015. On 19 August 2015 final reminder calls were made by telephone because only 50% of the interviewees had replied by that date. During 27 July–27 August 2015 interviewees' feedback was collected through email. A total of

21 (out of 27) interviewees replied by 27 August 2015 which is a response rate of 78% including insectary owners (8/9), researchers (8/9), and citrus growers (5/9).

Analysis of stakeholder feedback

Respondents' feedback included points of agreement and disagreement, some new discussion points and some additional recommendations. This feedback was summarised according to the three groups: insectary owners, researchers and citrus growers. These summaries are discussed below.

8.3 Stakeholder feedback discussion

A majority of the researchers (5/8) and insectary owners (6/8) raised questions about the barriers and recommendation in the summary report and added further opinions and recommendations. The remaining insectary owners and researchers did not add further comments. A few of the citrus growers (3/5) added further comments about the same problems that were already discussed in Chapter 6. Most of these comments and recommendations are discussed in previous Chapters 4, 5, 6 or 7. In this Chapter, insectary owners, researchers, and citrus growers' comments are discussed and expanded further.

One of the researchers raised a question about the necessity of commercial BCAs and stated:

> "Augmentative releases are not required in many instances – particularly in situations where disruptive pesticides are not used….. some growers will purchase natural enemies annually as a 'insurance policy' in order to ensure supply if pesticides/climate 'decimate' established populations in orchards."

Australian agriculture is becoming more export oriented. Different markets have different quality requirements and this is guiding growers' pest management practices. Other researchers noted that often the fresh market fruit is not allowed to have the same level of damage, especially cosmetic damage, as fruit for processing (Urquhart, 1999; Kaine and Bewsell, 2008). As a consequence, growers do not have a choice other than the use of pesticides. This study reveals that Chlorpyrifos (a broad spectrum insecticide) is widely used in citrus crops to avoid damage to the appearance of crops.

Within the agriculture system sometimes the natural biological control agents are either absent or failed to control the pests due to several factors such as climatic and geographic conditions, or lack of hosts or lack of food or developmental timing and cropping systems (Obrycki et al., 1997; Wissinger, 1997; Sivinski, 2013). A high proportion of agricultural insect pests are exotic species because they were introduced into Australia through the international agricultural products trade and tourism (Bin and Bruni, 1997). Natural enemies are absent or endemic natural enemies do not effectively control these exotic pests (New, 2002). Researchers need to consider all of these factors before making recommendations about the use of augmentative biological control or not to use commercial BCAs.

A few of the researchers raised questions about whether the organic cropping system is the appropriate target market for the industry. Another explained that when organic growers reduce or eliminate insecticide use then natural biological control agents move in automatically and they do not need to release commercial BCAs. Other researchers identified several other reasons such as organically registered pesticides and augmentation of commercial BCAs with the combination of other methods in organic farms may cause the commercial BCAs to be less effective than stand-alone use (Zehnder et al., 2007). Some researchers' pointed out that the organic grower achieved insufficient levels of pest control from naturally occurring biological control agents. The reliance on pyrethrum and *Bacillus thuringiensis* (Bt) is not sustainable, is expensive, and certainly not desirable in terms of pest management (Horne, 2007). The national and the International Federation of Organic Agriculture Movement (IFOAM) guideline recommend the use of parasitoids, predators and microbial commercial BCAs for pest management in organic farms (Zehnder et al., 2007; Neeson, 2007; Horne, 2007). One of the insectary owners pointed out that organic cropping is a very small part of production and not worth focusing on. The retail value of the 'organic market' in Australia was estimated at least $1 billion in 2010 with annual growth projections ranging from 10% to 25% for the years ahead (Monk, 2012). Therefore, this market is one of the windows of opportunity for the Australian insectary industry expansion.

One of the insectary owners believed that it is not possible to control all the pests with biological control. Some selective insecticides are needed in addition to commercial BCAs to achieve commercially acceptable outcomes. He pointed out that Australia is ten years behind Europe because the Europeans are supported by financial and legislative efforts in finding improved biological control solutions. They promote biological control and enforce more restrictions on pesticide use. In Chapter 5, the majority of the researchers believed that it is necessary to choose insecticides carefully so that they have sufficient efficacy on the pests. They also believed that selective insecticides may be benign on several groups of key beneficial insects but generally do still have significant toxicity to other groups of beneficial insects.

One of the researchers pointed out that insecticide resistance and insecticide withdrawal are the biggest drivers for the expansion of this industry. This occurs especially in greenhouses where pest insects developed resistance to insecticides very quickly because they reproduce faster and growers increased the frequency of insecticide application. One of the insectary owners also believed that currently their industry is growing due to insecticide resistance.

This same insectary owner raised a question about the biosecurity barrier. He believed that biosecurity is not a problem in the domestic market and the biosecurity issue for import of biological control agents into Australia protects the Australian insectary industry from overseas companies. Perhaps he does not need to send soil or plant material as host with commercial BCAs. Sometimes growers had to use chemicals due to the interstate biosecurity for Queensland fruit fly, and thus they could not use commercial BCAs. This insectary owner did not consider that most of the insects are introduced in Australia and the industry needed to import some exotic species of biological control agents for successful biological control.

Most of the insectary owners are not interested in patents because they believed that patents would not help the industry expansion. Different insectary owners expressed different opinions about patents including that patents are expensive and laborious. For example, an Australian standard patent for a single mechanical invention typically costs in the vicinity of AUD$30800 (including 10% Goods and Services Tax) for its 21 year life (http://www.wadesonip.com.au/patent-attorney-services/patents/patent-costs/). So their thinking is reasonable. To manage the patent costs the large insectaries could give licenses to the small companies. They also believe that the complexity of this technology would protect them. They think that patents are an impediment for the industry expansion because patents allow only the patent holder to rear that organism. Perhaps they did not consider the European and American insectaries or chemical companies that are patent protected and have expanded their businesses internationally.

One of the researchers agreed that some form of public subsidy is required like the European scheme to build a large hi-tech commercial production facility. A tax incentive to farmers who incorporate commercial BCAs into their IPM pest control practices might be an alternative. He also believed that this would address the barriers in Box 8.1 a, b and e.

Insectary owners agreed with Recommendation 4 (Box 8.1) that growers needed technical support to incorporate commercial BCAs into their pest management program. They added further comments on this recommendation. One of them identified that skill shortage is a major barrier because an IPM consultant is quite a demanding job requiring a lot of time spent in the field. There are not too many students who are graduating in entomology and plant protection in Australia nowadays. Perhaps the younger generation does not like these disciplines or the type of jobs available. This warrants further research. Perhaps the insectary industry needs to find alternatives.

Firstly this industry can develop technical support mobile phone apps for growers. They can use Skype (or an equivalent app) for technical support to the growers because currently all growers use a smart phone. They can easily connect with technical support staff through Skype. One technical support staff can support one-to-one or group based technical support from his/her office.

Secondly, perhaps insectary companies can find a volunteer grower in every crop growing area and educate that grower and give him support to develop a model farm. This industry can use him to educate growers as well as an advertising person. In Australia, in rural areas, communications are direct as people to people. Growers believe neighbours' messages rather than when told things by anyone else (Truscott, 2006).

Finally, this insectary industry needs to develop insect identification and monitoring flash cards (flash cards are photographic and descriptive of the various life stages and monitoring tips). In other countries, such as the USA, the grape industry developed 50 vineyard pest identification and monitoring cards (Varela and Bentley, 2011). These 50 information-rich cards help growers, vineyard managers, and their teams identify and manage most common problems. Similar types of cards are needed for every crop which will help to reduce monitoring costs as well.

Citrus growers raised a question that where will they find the right commercial BCAs. Growers do not have time to search for commercial BCAs or read everything on the insectary companies' websites because most of the growers work long physical days. Insectary companies can establish rearing facilities or a retail office in different states or crop-growing regions or they can find retail agents in every cropping area. This will enable growers to easily access the sources of commercial BCAs.

This industry needs to create its own market. The government can introduce new laws, give research support to this industry or incentive to the growers. They can make it favourable for them but cannot create their market for them.

8.4 Recommendations

This study discussed and synthesised the results and made some recommendations.

1. Patents (rearing information and pest control techniques because free living organisms cannot be patented) are essential for expansion of the Australian insectary industry because without patent the insectary owners keep secret rearing methods and pest control techniques. They are cautious to train people for technical support but growers need technical support to adopt commercial BCAs. The insectary owners need to change their attitude towards the patent system and like the European and the American insectary owners support patent protection.

2. The Australian insectary owners need collaboration within this industry, between the industries (different crops) and with other research organisations. Collaboration is essential for the actual implementation of commercial BCAs.

3. The Australian insectary owners need a multi-target approach to develop a new commercial BCA which controls a key pest of multiple crops or controls multiple key pests. This can also reduce the production costs by use of one rearing host (such as host insects, soil, plants, fruit, vegetables, or other natural and artificial diets) for the production of multiple commercial BCAs.

4. Growers (especially small farm owners) need technical support to incorporate commercial BCAs into their pest management program. Insectary companies can overcome technical support skill shortage in several ways:

   i. The Australian insectary industry can develop technical support software for growers such as phone apps. Insectary owners can also give technical support through Skype (or an equivalent program).

   ii. The Australian insectary companies need to educate growers through a model grower in each cropping area because rural Australia operates with people and communication works directly.

   iii. This industry needs to develop insect identification and monitoring flash cards that will reduces the monitoring costs substantially and help to manage most common problems that are caused by insects.

5. More species of commercial BCAs are necessary to manage all of the pests in a particular crop. For instance in citrus crops growers face several major pest problem but only three commercial BCAs (*Aphytis* spp., *C. montrouzi*eri and *M. signata*) are

available. Although these commercial BCAs control multiple pests more species or other techniques are all needed to control all of the pests.

6. For consumers' education the insectary companies can establish IPM shops or contact local shops that sell fresh produce and encourage them to sell IPM grown fresh produce and play videos that will show how these products are grown. The introduction of an IPM logo for fresh produce will encourage consumers to ask supermarket for products displaying with appropriate labels or logo. In many countries, private organisations set standards for the certification of agricultural products around the world such as GLOBALGAP. Integrated Pest Management is one of the essential parts of its guidelines (van Lenteren, 2012). Television and radio programs will also increase consumers' awareness.

7. To ensure that growers can easily access the sources of commercial BCAs, insectary companies can establish a retail office in different states or crop growing regions or find retail agents in every cropping area.

8. The organic market is expanding considerably. Very few organic growers use commercial BCAs. The insectary industry needs to focus on organic farmers and encourage their uptake of commercial BCAs. The retail value of this industry was estimated AUD$ 1 billion in 2010 with annual growth projections 10%–25% for the years ahead (Monk 2012).

9. The Australasian Biological Control Association Inc. needs to join with other related associations (such as The Entomological Society of Australia) to form a lobby group to convince government to support this industry.

10. Pest management consultants and extension officers require some education about IPM or commercial BCAs because they are the agents to change growers' attitude and establish growers' confidence in IPM or commercial BCAs.

8.5 Overall conclusions

This study constitutes the first report of the Australian commercial insectary industry. It shows how this industry started with citrus pest management in the 1970s and then expanded in a certain period (1991–2001) based on one pest (two-spotted spider mite) that developed insecticide resistance to multiple insecticides. Then this expansion ceased and currently the industry faces many barriers such as insectary set-up cost, lack of research support, bringing a new species into the pest control market, logistic problems, interstate biosecurity problems, skill shortage and market competition.

The market for commercial BCAs is very limited and there is no export market. The industry is primarily horticulture based in Australia. Commercial BCAs are mainly used in greenhouses (in Europe) but in Australia greenhouses are a very small proportion of the total production compared with broad acre cropping systems. Only a few organic growers use commercial BCAs.

The most important finding of the citrus growers' survey is the farm size (economic factor) that has a large impact on the adoption of commercial BCAs. Users of commercial BCAs have larger farms, more employees and achieved higher crop values per year than non-users. Users also usually work with a consultant. The study also revealed that the complexity of the adoption of commercial BCA is the main reason that deterred small farm owners from adopting it. They needed technical support which was not economically available to them. Skill shortage is one of the major barriers that prevented insectary owners from giving technical support to growers. This industry needs to find alternative ways to support growers and this study identified several potential options for them.

This study identified that protectiveness is one of the major barriers for this industry expansion. Perhaps the reluctance to train people contributes to the shortage of skills described above. The Australian insectary owners are always concerned about competitors because there were no patents for the rearing or other technologies in Australia except for nematodes. This study also identified how patents will help the industry expansion.

The Australian insectary owners, policy makers, IPM researchers and practitioners need to take these recommendations (Section 8.4) into consideration to expand this industry. Several areas warrant further research to better understand the adoption of commercial BCAs. These areas are: promotion of commercial BCAs, selective insecticide use in IPM, commercial BCA use in the organic cropping system, market competition, patent protection, collaboration, skill shortage and protectiveness. Perhaps commercial confidentiality may be one of the important impediments for the expansion of this industry. Further study is needed to analyse the dynamics or changing aspects of commercial BCA adoption. The same growers should be followed by analysing the costs and benefits before and after the adoption of commercial BCAs. The present expansion is far behind what might be expected. The major impacts on the insectary industry expansion, patents, collaboration and government support are summarised in Figure 8.1.

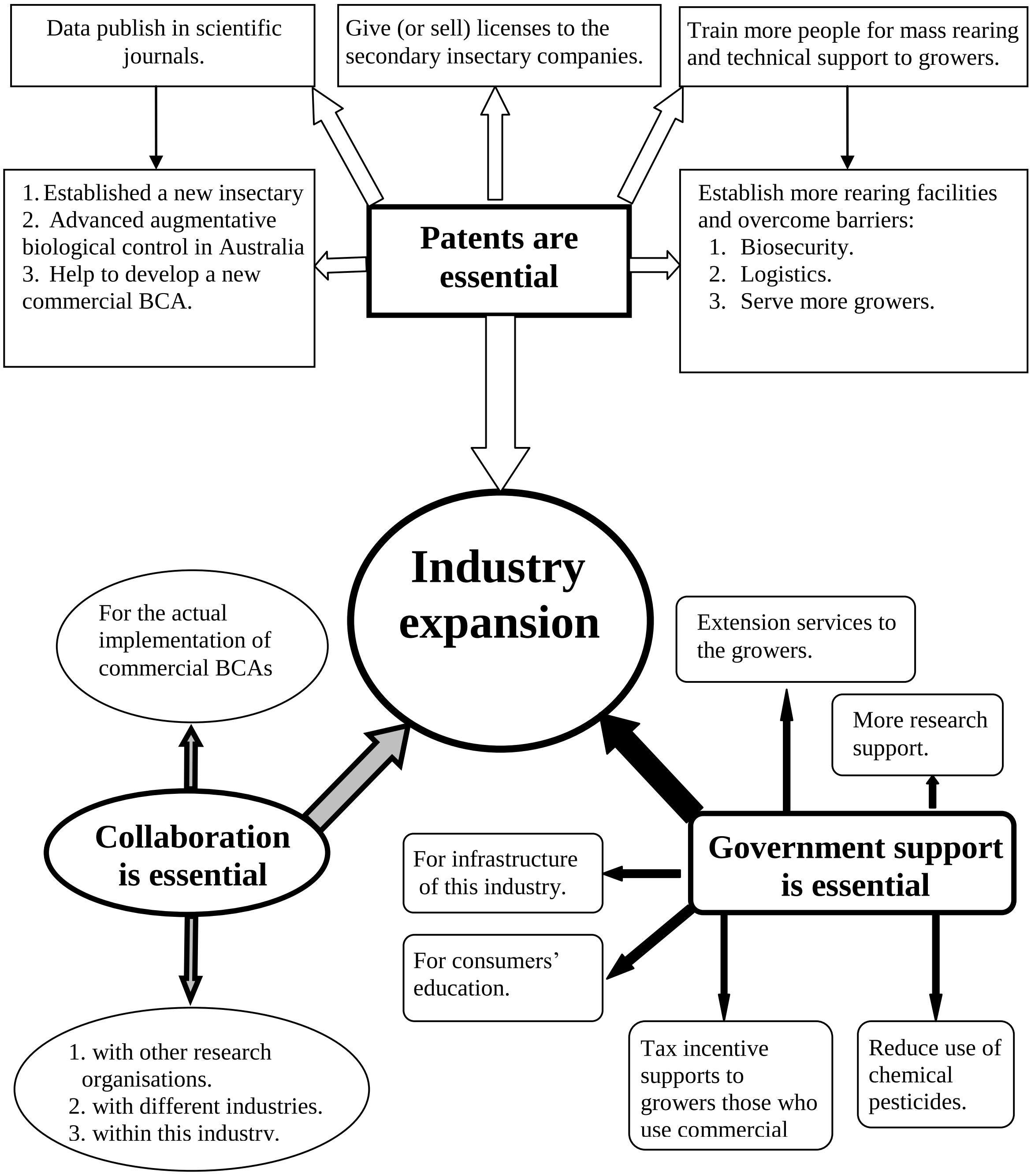

Figure 8.1: The patents, collaboration and the government support have major impacts on the insectary industry expansion.

References

ABS (2003). "Australian social trends." Australian Bureau of Statistics, Canberra, Australia.

ABS (2011). Census of Population and Housing. Australian Bureau of Statistics, Canberra, Australia.

ABS (2012). Agricultural Commodities, Australia, 2009–10. Canberra, Australia.

Adesina, A., and Zinnah, M. (1993). Technology characteristics, farmers' perceptions and adoption decisions: A Tobit model application in Sierra Leone. *Agricultural Economics* **9**, 297–311.

Ager, A., and Loughry, M. (2004). Psychology and Humanitarian Assistance. *The Journal of Humanitarian Assistance* (Online). (Accessed 22 July 2015).

Agriculture Today (2010). Wasps to the rescue against fruit flies. http://www.dpi.nsw.gov.au/archieve/agriculture-today, (Accessed 15 September 2015).

Akudugu, M. A., Guo, E., and Dadzie, S. K. (2012). Adoption of Modern Agricultural Production Technologies by Farm Householders in Ghana: What Factors Influence their Decisions? *Journal of Biology, Agriculture and Healthcare* **2**, 2224–3208.

Allen, W., Kilvington, M., Nixon, C., and Yeabsley, J. (2002). Sustainable Development Extension. Ministry of Agriculture and Forestry (MAF). http://www.maf.govt.nz/MAFnet/publications/agext, (Accessed 22 July 2015), MAF Technical Paper No. 2002/03, p80, Wellington, New Zealand.

Anonymous (2005). Spotlight on biopesticides. *In* "Crop Protection Monthly, 31 March 2005 - Issue 184", pp. 10–17. Market Scope Europe Ltd, http://www.crop-protection-monthly.co.uk, (Accessed 18 September 2015).

Bajwa, W. I., and Kogan, M. (2002). Compendium of IPM Definitions (CID) - What is IPM and how is it defined in the Worldwide Literature? IPPC Publication No. 998, Integrated Plant Protection Center (IPPC), Oregon State University, Corvallis, OR 97331, USA.

Bajwa, W. I., and Kogan, M. (2003). Integrated pest management adoption by the global community. *In* "Integrated pest management in the global arena" (K. M. Maredia, D. Dakouo and D. Mota-Sanchez, eds.), pp. 97–107. CABI Publishing, Wallingford UK.

Baker, G. J., Keller, M. A., P. Crisp, P., Jackman, D., Barbour, D., and Purvis, S. (2011). The biological control of Kelly's citrus thrips in Australian citrus orchards. *Integrated Control in Citrus Fruit Crops IOBC/wprs Bulletin* **62**, 267–274.

Baker, K. F. (1987). Evolving concepts of biological control of plant pathogens. *Annual Review of Phytopathol* **25**, 67–85.

Barungi, M., Ng'ong'ola, D. H., Edriss, A., Mugisha, J., Waithaka, M., and Tukahirwa, J. (2013). Factors Influencing the Adoption of Soil Erosion Control Technologies by Farmers along the Slopes of Mt. Elgon in Eastern Uganda. *Journal of Sustainable Development* **6**, 9–25.

Batz, F. J., Peters, K. J., and Janssen, W. (1999). The influence of technology characteristics on the rate and speed of adoption. *Agricultural Economics* **21**, 121–130.

Begum, M., Gurr, G. M., Wratten, S. D., Hedberg, P. R., and Nicol, H. I. (2006). Using selective food plants to maximize biological control of vineyard pests. *Journal of Applied Ecology* **43**, 547–554.

Bera, R. K. (2009). Post–1980 World of Biotechnology Patents in the US. *Current Science* **96**, 1343–1348.

Bernard, R. H. (1988). Research methods in cultural anthropology. pp. 177. Sage, Newbury Park, CA, USA.

Bigler, F. (2006). The use of invertebrates for biological control of arthropods in Europe: successes and challenges. *Phytoma*, 19–23.

Bijman, J., Ton, G., and Meijerink, G. (2007). "Empowering Small holder Farmers in Markets: National and International Policy Initiatives," WUR: Wageningen, The Netherlands.

Bin, F., and Bruni, R. (1997). Evaluating one century of classical biocontrol in Italy. *EPPO Bulletin* **27**, 53–59.

Blockmans, K. J. F. (1999). Commercial aspects of biological pest control. *In* "Integrated Pest and Didease Management in Greenhouse Crops" (R. Albajes, M. I. Gullino, J. C. van Lenteren and Y. Elad, eds.), pp. 310–318. Kluwer Publishers, Dordrecht, The Netherlands.

Bonabana-Wabbi, J., and Taylor, D. B. (2012). A Limited Dependent Variable Analysis of Integrated Pest Management Adoption in Uganda. *Journal of Agricultural Science and Technology* **2**, 1162–1174.

Bruges, M., and Smith, W. (2008). Participatory approaches for sustainable agriculture: A contradiction in terms? *Agriculture and Human Values* **25**, 13–23.

Bryman, A., and Bell, E. (2007). Business Research Methods, 2nd ed. Oxford University Press Oxford, UK.

Bueno, R. C. O. F., Bueno, A. F., Moscardi, F., Parrad, J. R. P., and Hoffmann-Campob, C. B. (2011). Lepidopteran larva consumption of soybean foliage: basis for developing multiple-species economic thresholds for pest management decisions. *Pest Management Science* **67**, 170–174.

Bugs for Bugs (2015). Is Bugs for Bugs growing! *In* "Bugs for Bugs Update, Autumn 2015". http://www.bugsforbugs.com.au/, (Accessed 1 May 2015).

Caltagirone, L. (1981). Landmark examples in classical biological control. *Annual Review of Entomology* **26**, 213–232.

Cameron, P. J. (2007). Factors influencing the development of integrated pest management (IPM) in selected vegetable crops: a review. *New Zealand Journal of Crop and Horticultural Science* **35**, 365–384.

Cancino, J., and Montoya, P. (2006). Advances and perspectives in the mass rearing of fruit fly parasitoids in Mexico. *In* "Fruit Flies of Economic Importance: From Basic to Applied Knowledge, Proceedings of the 7th International Symposium on Fruit Flies of Economic Importance10-15 September 2006", pp. 133–142, Salvador, Brazil.

Cannell, E. (2007). European farmers plough ahead pesticide use reduction. *Pesticides News* **78**, 3–5.

Carter, J. L. (2008). Thinking outside the framework: equitable research partnerships for environmental research in Australia. *The Geographical Journal* **174**, 63–75.

CGIAR (2005). Innovation is rewarded at 2005 World Bank Development Marketplace. Consultative Group on International Agricultural Research. http://www.cgiar.org/web-archives/www-cgiar-org-monthlystory-june2005-html/, (Accessd 28 July 2015).

Chaves, B., and Riley, J. (2001). Determination of factors influencing integrated pest management adoption in coffee berry borer in Colombian farms. *Agricultural, Ecosystems and Environment* **87**, 159–177.

Cherry, A. J., and Gwynn, R. L. (2007). Perspectives on the development of biological control agents in Africa. *Biocontrol Science and Technology* **17**, 665–676.

Chi, T. T. N., and Yamada, R. (2002). Factors affecting farmers' adoption of technologies in farming system: A case study in OMon district, Can Tho province, Mekong Delta. *Omonrice* **10**, 94–100.

Citrus Australia Ltd. (2011). Citrus industry annual report 2011. Horticulture Innovation Australia Limited (HIAL), Australia.

Cock, M. J. W., van Lenteren, J. C., Brodeur, J., Barratt, B. I. P., Bigler, E., Bolckmans, K., Consoli, L. F., Haas, F., Mason, G. P., and Parra, J. R. P. (2009). The use and exchange of biological control agents for food and agriculture. Background Study Paper No. 47. pp. 88. Commission on Genetic Resources for Food and Agriculture, FAO, ftp://ftp.fao.org/docrep/fao/meeting/017/ak569e.pdf (Accessed 15 September 2015), Rome, Italy.

Cock, M. J. W., van Lenteren, J. C., Brodeur, J., Barratt, B. I. P., Bigler, E., Bolckmans, K., Consoli, L. F., Haas, F., Mason, G. P., and Parra, J. R. P. (2010). Do new Access and Benefit Sharing Procedures under the Conservation on Biological Diversity threaten the future of biological control. *BioControl* **55**, 199–218.

Cohen, L., Manion, L., and Morrison, K. (2007). "Research methods in education (6th ed.)," Routledge, New York, USA.

Cohen, S. (2010). Center for Regulatory Research. In "Bio-control Matters". Association of Natural Biocontrol Producers, Minnesota, USA.

Collier, T., and Steenwyk, R. V. (2004). A critical evaluation of augmentative biological control. *Biological Control* **31**, 245–256.

Collins, P. J., Lambkin, T. M., and Bodnaruk, K. P. (1994). Suspected Resistance to Methidathion in *Aonidiella aurantii* (Maskell) (Hemiptera: Diaspididae) from Queensland. *Australian Journal of Entomology* **33**, 325–326.

Colloff, M. J., Lindsay, E. A., and Cook, C. D. (2013). Natural pest control in citrus as an ecosystem service: Integrating ecology, economics and management at the farm scale. *Biological Control* **67** 170–177.

Cranshaw, W., Sclar, D. C., and Cooper, D. (1996). A review of 1994 pricing and marketing by suppliers of organisms for biological control of arthropods in the United States. *Biological Control* **6**, 291–296.

Cumming, G. S., and Spiesman, B. J. (2006). Regional problems need integrated solutions: Pest management and conservation biology in agroecosystems. *Biological Conservation* **131**, 533–543.

Daane, K. M., Mills, N. J., Warner, K. D., and Getz, C. (2007). "Biological Control of Arthropod Pests in California Agriculture: Current Status and Future Potential." California Department of Food and Agriculture, Sacramento, CA, USA.

Daberkow, S., and McBride, W. (2003). Farm and operator characteristics affecting awareness and adoption of precision agriculture technologies in the US. *Precision Agriculture* **4**, 163–177.

Dao, T. H. (2012). Ecology of red scale (*Aonidiella aurantii* (Maskell) (Hemiptera: Sternorrhyncha: Diaspididae) in citrus orchards on the Central Coast of New South Wales. PhD thesis, University of Western Sydney, Australia.

Davidson, S. (2001). Dirty Deeds. *Ecos* **106**, 12–14.

DeBach, P. (1964). The scope of biological control. *In* "Biological Control of Insect Pests and Weeds" (P. DeBach, ed.), pp. 3–20. Reinhold Publisher, New York, USA.

DeBach, P. (1974). Preface. *In* "Biological Control by Natural Enemies" (P. DeBach and D. Rosen, eds.). Cambridge University Press, Cambridge, UK.

DeBarro, P. J., and Coombs, M. T. (2009). Post-release evaluation of *Eretmocerus hayati* Zolnerowich and Rose in Australia. *Bulletin of Entomological Research* **99**, 193–206.

DeBuck, A. J., and Beerling, E. A. M. (2006). Implementation of Biocontrol and IPM in Dutch Horticulture. *In* "An Ecological and Societal Approach to Biological

Control" (J. Eilenberg and H. M. T. Hokkanen, eds.), pp. 73–90. Springer, The Netherlands.

Denoth, M., Frid, L., and Myers, J. H. (2002). Multiple agents in biological control: improving the odds? *Biological Control* **24**, 20–30.

Dent, D. (2000). "Insect Pest Management," CABI Publishing, Wallingford, UK.

Devine, G. J., and Furlong, M. J. (2007). Insecticide use: contexts and ecological consequences. *Agriculture and Human Values* **24**, 281–306.

Diane, T. F., Jean, W., and Ann, E. M. (2002). The cultural context of adjusting to nursing home life : Chinese elders' perspectives. *The Gerontologist* **42**, 667–675.

DiCicco-Bloom, B., and Crabtree, B. F. (2006). The qualitative research interview. *Medical Education* **40**, 314–321.

Dietrick, E. J. (1981). Commercial production of entomophagous inscts and their successful use in agriculture. *In* "Beltsville Symposia in Agriculture Research, Biological Control in Crop Protection" (C. C. Papavizas, ed.), pp. 151–160, Allenheld, Osmun, London, UK.

Doss, C. R. (2003). Understanding Farm Level Technology Adoption: Lessons Learned from CIMMYT's Micro Surveys in Eastern Africa. CIMMYT Economics Working Paper 03–07. Mexico, D.F.: CIMMYT.

Doutt, R. L. (1964). The historicl development of biological control *In* "Biolgical Control of Insect Pest and Weeds" (P. DeBach, ed.). Chapman and Hall, London,UK.

Drlik, T. (1995). Everett Dietrick - Biological Control Pioneer. *The IPM Practitioner* **17**, 15.

Edge, V. E., and James, D. G. (1982). Detection of cyhexatin resistance in two-spotted mite,*Teranychus urticae* Koch (Acari: Tetranychidae) in Australia. *Journal of the Australian Entomological Society* **21**, 198.

Edge, V. E., and James, D. G. (1986). Organo-tin Resistance in *Tetranychus urticae* (Acari: Tetranychidae) in Australia. *Journal of Economic Entomology* **79**, 1477–1483.

Ehler, L. E. (1991). Use of Commercial Biological Control Agents for Insects and Mites. Small Farm Center, University of California, Davis, CA 95616, USA.

Ehler, L. E. (1998). Conservation Biological Control: past, present and future. *In* "Conservation Biological Control" (P. Barbosa, ed.), pp. 1–8. Academic Press, San Diego, CA, USA.

Ehler, L. E., and Bottrell, D. G. (2000). The illusion of integrated pest management. *Issues in science and technology* **16**, 61–64.

Eilenberg, J. (2006). Concepts and Visions of Biological Control. *In* "An Ecological and Societal Approach to Biological Control" (J. Eilenberg and H. M. T. Hokkanen, eds.), pp. 1–12. Springer, Dordrecht, The Netherlands.

Eilenberg, J., Hajek, A., and Lomer, C. (2001). Suggestions for unifying the terminology in biological control. *BioControl* **46**, 387–400.

Eilenberg, J. R., Enkegaard, A., Vestergaard, S., and Jensen, B. (2000). Biocontrol of Pests on Plant Crops in Denmark: Present Status and Future Potential. *Biocontrol Science and Technology* **10**, 703–71.

English-Loeb, G., Rhainds, M., Martinson, T., and Ugine, T. (2003). Influence of flowering cover crops on Anagyrus parasitoids (Hymenoptera: Mymaridae) and Erythoneura leafhoppers (Homoptera: Cicadellidae) in New York vineyards. *Agricultural and Forest Entomology* **5**, 173–181.

Escalada, M. M., and Heong, K. L. (1997). Methods for research on farmers' knowledge, attitudes, and practices in pest management. *In* "Pest Management of Rice Farmers' in Asia" (K. L. Heong and M. M. Escalada, eds.), pp. 1–34. International Rice Research Institute, Los Banos, Philippines.

FAO (1967). Report of the Session of the FAO Panel of Experts on Integrated Pest Control *In* "Food and Agriculture Organization of the United Nations, 1st September", Rome, Italy.

Feder, G., Just, R., and Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change* **33**, 255–298.

Feder, G., and Umali, D. L. (1993). The adoption of agricultural innovations: A review. *Technological Forecasting and Social Change* **43**, 215–239.

Fernandez-Cornejo, J. E. (1996). The microeconomic impact of IPM adoption: Theory and application. *Agricultural and Resource Economic Review* **25**, 149–160.

Fielding, N. (2012). Triangulation and Mixed Methods Designs: Data Integration With New Research Technologies. *Journal of Mixed Methods Research* **6**, 124-136.

Fitt, G., and Wilson, L. (2012). Integrated Pest Management for Sustainable Agriculture. *In* "Integrated Pest Management: Principles and Practices" (D.P.Abrol and U.Shankar, eds.), pp. 27–40. CABI, Wallingford, UK.

Fitzpatrick, C. (2011). "Citrus industry annual report 2011." Horticulture Innovation Australia Limited (HIAL), Australia.

Franklin, B., and Osborne, H. (1971). "Research Methods: Issues and Insights," Wadsworth Publishing Co Inc., Belmont, NY, USA.

Frisbie, R. E., and Smith, J. W. J. (1991). Biologically intensive integrated pest management: the future. *In* "In Progress and Perspective for the 21st Century" (J. J. Menn and A. L. Steinhauer, eds.), pp. 151–64. Entomological Society of America, Lanham Maryland, USA.

Furlong, M. J., Shi, Z. H., Liu, Y. Q., Guo, S. J., Lu, Y. B., Liu, S. S., and Zalucki, M. P. (2004). Experimental analysis of the influence of pest management practice on the efficacy of an endemic arthropod natural enemy complex of the diamondback moth. *Journal of Economic Entomology* **97**, 1814–1827.

Furlong, M. J., Spafford, H., Ridland, P. M., and *et.al.* (2008). Ecology of diamond-back moth in Australian canola: landscape perspectives and the implications for management. *Australian Journal of Experimental Agriculture* **48**, 1494–1505.

Furness, G. O., Buchanan, G. A., George, R. S., and Richardson, N. L. (1983). A history of the biological and integrated control of red scale, *Aonidiella aurantii* on citrus in the lower Murray Valley of Australia. *Entomophaga* **3**, 199–212.

Garcia, R., Caltagirone, L., and Gutierrez, A. (1988). Comments on a redefinition of biological control. *BioScience* **38**, 692–694.

Gardner, J., Hoffmann, M. P., Pitcher, S. A., and Harper, J. K. (2011). Integrating insecticides and *Trichogramma ostriniae* to control European corn borer in sweet corn: Economic analysis. *Biological control* **56**, 9–16.

Geier, P. W., and Clark, L. R. (1961). An ecological approach to pest control. *In* "Proceedings of the Eighth Technical Meeting. International Union of Conservation of Nature and Natural Resources, Warsaw 1960", pp. 10–18., Warsaw, Poland.

Geiger, F., Bengtsson, J., Berendse, F., Weisser, W., Emmerson, M., Morales, M. B., Ceryngier, P., Liira, J., Tscharntke, T., Winqvist, C., Eggers, S., Bommarco, R., Part, T., Bretagnolle, V., Plantegenest, M., Clement, L., Dennis, C., Palmer, C., Onate, J. J., Guerrero, I., Hawro, V., Aavik, T., Thies, C., Flohre, A., Hanke, S., Fischer, C., Goedhart, P. W., and Inchausti, P. (2010). Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic Applied Ecology* **11**, 97–105.

Gentz, M. C., Murdoch, G., and King, G. F. (2010). Tandem use of selective insecticides and natural enemies for effective, reduced-risk pest management. *Biological Control* **52**, 208–215.

Georghiou, G. P. (1983). Management of resistance in arthropods. *In* "Pest Resistance to Pesticides" (G. P. Georghiou and T. Saito, eds.), pp. 769–792. Plenum Press, New York, USA.

Georgis, R., Koppenho¨ ferb, A. M., Laceyc, L. A., Be´laird, G., Duncane, L. W., Grewalf, P. S., Samishg, M., Tanh, L., Torri, P., and van Tolj, R. W. H. M. (2006). Successes and failures in the use of parasitic nematodes for pest control. *Biological Control* **38**, 103–123.

Glenister, C. S. (2004). Rules and regulations governing commercial insectaries. *In* "California Conference on Biological Control IV, Berkeley, California, USA, 13-15 July, 2004.", pp. 83–87. Center for Biological Control, College of Natural Resources, University of California, CA, USA.

Goolsby, J., De Barro, P., Hoelmer, K., and Kirk, A. (2005). Retrospective evaluation of the biological control program for *Bemisia tabaci* biotype "B" in the USA. *In* "Second International Symposium on Biological Control of Arthropods" (M. S. Hoddle, ed.), Vol. 1, pp. 144–153. University of California, Riverside USA, USDA Forest Service Publication FHTET–2005–08, Davos, Switzerland.

Graebner, L., Moreno, D. S., and Baritelle, L. L. (1984). The Fillmore Protective District: a success story in integrated pest management. *Bulletin of the Entomological Society of America* **30**, 27–33.

Grafton-Cardwell, E. E., Ouyang, Y., Striggow, R., and Vehrs, S. (2001). Armored scale insecticide resistance challenges San Joaquin Valley citrus growers. *California Agriculture* **55** 20–25.

Greathead, D. J., and Greathead, A. H. (1992). Biological control of insect pests by insect parasitoids and predators. *Biocontrol News and Information, BIOCAT database* **13**, 61–68.

Grieshop, J. I., Zalom, F. G., and Miyao, G. (1988). Adoption and diffusion of integrated pest management innovations in agriculture. *Bulletin of Entomological Societ of America* **34**, 72–78.

Grogan, K. A., and Goodhue, R. E. (2012). Citrus growers vary in their adoption of biological control. *California Agriculture* **66**, 29–36.

Guillon, M. (2004). Current world situation on acceptance and marketing of biological control agents. Position Paper. International Biocontrol Manufacturers Association, Brussels, Belgium.

Gurr, G. M., Barlow, N. D., Memmott, J., Wratten, S. D., and Greathead, D. J. (2000). A History of Methodological, Theoretical and Empirical Approaches to Biological Control. *In* "Biological Control: Measures of Success" (G. M. Gurr and S. Wratten, eds.), pp. 3–37. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Gurr, G. M., Horne, P., Page, J., Ash, G. J., and Pilkington, L. J. (2010). Australia and New Zealand biocontrol conference: Emerging themes, future prospects. *Biological Control* **52**, 195–197.

Gurr, G. M., and Kvedaras, O. L. (2010). Synergizing biological control: Scope for sterile insect technique, induced plant defences and cultural techniques to enhance natural enemy impact. *Biological Control* **52**, 198–207.

Hajek, A. E. (2004). "Natural enemies: an introduction to biological control," Cambridge University Press, UK.

Hale, M. A., and Elliott, D. (2003). Successes and Challenges in Augmentative Biological Control in Outdoor Agricultural Applications: A Producer's Perspective. *In* "Proceedings of First International Symposium on Biological control of Arthropods", pp. 185–188, Honolulu, HI, USA.

Hammond, C. M., Luschei, E. C., Boerboom, C. M., and Nowak, P. J. (2006). Adoption of Integrated Pest Management Tactics by Wisconsin Farmers. *Weed Technology* **20**, 756–767.

Harper, J. K., Rister, M. E., Mjelde, J. W., Drees, B. M., and Way, M. O. (1990). Factors influencing the adoption of insect management technology. *American Journal of Agricultural Economics* **72**, 997–1005.

Hay, R., and Pearce, P. L. (2014). Technology adoption by rural women in Queensland, Australia: Women driving technology from the homestead for the paddock. *Journal of Rural Studies* **36**, 318–327.

Herbert, D. A. J. (1995). Integrated Pest Management Systems: Back to Basics to Overcome Adoption Obstacles. *Journal of Agricultural Entomolgy* **12**, 203–210.

Herron, G., Edge, V., and Rophail, J. (1993). Clofentezine and hexythiazox resistance in *Tetranychus urticae* Koch in Australia. *Experimental and Applied Acarology* **17**, 433–440.

Herron, G. A., Rophail, J., and Wilson, L. J. (2001). The development of bifenthrin resistance in two-spotted spider mite (Acari: Tetranychidae) from Australian cotton. *Experimental and Applied Acarology* **25**, 301–310.

Holt, R. D., and Hochberg, M. E. (1997). When is biological control evolutionarily stable (or is it)? *Ecology* **78**, 1673–1683.

Horne, A. P. (2007). Pest Management for Organic Agriculture pp. 25. Rural Industries Research and Development Corporation Barton ACT 2600, Australia.

Horne, P. A., and Page, J. (2008). IPM for Crops and Pestures. (CSIRO, ed.). Landlinks Press, Melbourne, Australia.

Horne, P. A., Page, J., and Nicholson, C. (2008). When will integrated pest management strategies be adopted? Example of the development and implementation of integrated pest management strategies in cropping systems in Victoria. *Australian Journal of Experimental Agriculture* **48**, 1601–1607.

Howley, P., Donoghue, C. O., and Heanue, K. (2012). Factors Affecting Farmers' Adoption of Agricultural Innovations: A Panel Data Analysis of the Use of Artificial Insemination among Dairy Farmers in Ireland. *Journal of Agricultural Science* **4**, 171–179.

Hoy, M. (2009). Biological control of arthropod pests: traditional and emerging technologies. *American Journal of Alternative Agriculture* **3**, 63–68.

Huang, N., Enkegaard, A., Osborne, L. S., Ramakers, P. M. J., Messelink, G. J., Pijnakker, J., and Murphy, G. (2011). The Banker Plant Method in Biological Control. *Critical Reviews in Plant Science* **30**, 259–278.

Hunter, C. D. (1997). Suppliers of Beneficial Organisms in North America. *In* "Department of Pesticide Regulation, California Environmental Protection Agency", pp. 34, Sacramento, California, USA.

Huwer, R. K., Maddox, C. D. A., Fay, H. A. C., Llewellyn, R., Danne, A., Hickey, M., Melville, P., Burnett, J., Allen, A., and Groves, I. (2011). A multi target approach to fruitspotting bug management. *In* "Proceedings VII World Avocado Congress 2011", Cairns, Australia.

Ingels, C., Horn, M. V., Bugg, R. L., and Miller, P. R. (1994). Selecting the right cover crop gives multiple benefits. *California Agriculture* **48**, 43–48.

Irvin, N. A., and Hoddle, M. S. (2015). The Effect of Buckwheat Flowers and Cahaba Vetch Extrafloral Nectaries on Fitness of the Vine Mealybug Parasitoid *Anagyrus pseudococci* (Hymenotpera:Encyrtidae). *Florida Entomologist* **98**, 237–242.

Jackson, E., Quaddus, M., Islam, N., and Stanton, J. (2006). Hybrid vigour of behavioural theories in the agribusiness research domain. Is it possible? *Journal of Internatinal Farm Management* **3**, 1–15.

Javier, S. I. F., Frank, G. Z., and Francisco, L. J. (2010). A Review of Recent Patents on Macroorganisms as Biological Control Agents. *Recent Patents on Biotechnology* **4**, 48–64.

Jensen, H. G., Walker, T. S., and Barker, R. (1990). Adoption Ceilings and Modern Coarse Cereal Cultivers in India. *American Journal of Agricultural Economics* **92**, 753–763.

Jonsson, M., Wratten, S. D., Landis, D. A., and Gurr, G. M. (2008). Recent advances in conservation biological control of arthropods by arthropods. *Biological Control* **45**, 172–175.

Julien, M. H., Scott, J. K., Orapa, W., and Paynter, Q. (2007). History, opportunities and challenges for biological control in Australia, New Zealand and the Pacific islands. *Crop Protection* **26**, 255–265.

Kaine, G., and Bewsell, D. (2008). Adoption of Integrated Pest Management by apple growers: the role of context. *International Journal of Pest Management* **54**, 255–265.

Kajornboon, A. B. (2005). Using interviews as research instruments. E-Journal for Researching Teachers (EJRT), http://www.culi.chula.ac.th/e-Journal/bod/Annabel.pdf, (Accessed 15 September 2015).

King, E. C., Hopper, K. R., and Powell, J. E. (1985). Analysis of systems for biological control of crop arthropod pests in the U.S. by augmentation of predators and parasites. *In* "Biological control in agricultural IPM systems" (M. A. Hoy and D. C. Herzog, eds.), pp. 201–227. Academic Press, London, UK.

Knight, K. M. M., and Gurr, G. M. (2007). Review of Nezara viridula (L.) management strategies and potential for IPM in field crops with emphasis on Australia. *Crop Protection* **26**, 1–10.

Kogan, M. (1998). Integrated pest management: historical perspectives and contemporary developments. *Annual Review of Entomology* **43**, 243–270.

Landis, D. A., and Orr, D. B. (1996). Biological control: approaches and applications. *In* "Department of Entomology and Pesticide Research Center". Michigan State University, USA.

Lee, D. R. (2005). Agricultural Sustainability and Technology Adoption: Issues and Policies for Developing Countries *American Journal of Agricultural Economics* **87**, 1325–1334.

Lennie, J. (2006). Increasing the rigour and trustworthiness of participatory evaluations: learnings from the field. *Evaluation Journal of Australasia* **6**, 27–35.

Lewis, W. J., van Lenteren, J. C., Phatak, S. C., and Tumlinson, J. H. (1997). A total systems approach to sustainable pest management. *Proceedings of the National Academy of Sciences of the United States of American Entomologist* **94**, 12243–12248.

Li, J., Gómez, M., Rickard, B. J., and Skinner, M. (2011). Factors Influencing Adoption of Integrated Pest Management in Northeast Greenhouse and Nursery Production.Working Paper, Dyson School of Applied Economics and Management. pp. 1–36. Cornell University, New York, USA.

Li, L.-Y. (1994). Worldwide use of *Trichogramma* for biological control on differnt crops: a survey. *In* "Biological Control with Egg Parasitoids" (E. Wajnberg and S. A. Hassan, eds.), pp. 37–54. CAB International, Wallingford, UK.

Lionberger, H. F. (1960). Adoption of New Ideas and Practices. University Press, Iowa State, USA.

Lithourgidis, A. S., Dordas, C. A., Damalas, C. A., and Vlachostergios, D. N. (2011). Annual intercrops: an alternative pathway for sustainable agriculture. *Australian Journal of Crop Science* **5**, 396–410.

Llewellyn, R. (2006). Achieving rapid adoption:information value and the role of grower groups. pp. 13. Proceedings of the 13th Australian Agronomy Conference. Australian Society of Agronomy, Perth, WA.

Llewellyn, R. S., Papacek, D., Altmann, J., Ryland, A., Seymour, J., Steiner, M., Wilson, C., Horne, P., Proctor, R., Thompson, J., and Grundy, P. (2002). The Good Bug Book. (R. Llewellyn, ed.). Integrated Pest Management Pty Ltd, Australia.

Lockeretz, W. (1991). The organization and coverage of research on reduce use of agricultural chemicals. *Agricultural, Ecosystems and Environment* **36**, 217–234.

Luck, R. F., and Forster, L. D. (2003). Quality of augmentative biological control agents: a historical perspective and lessons learned from evaluating *Trichogramma*. *In* "Quality control and production of biological control agents: theory and testing procedures" (J. C. van Lenteren, ed.), pp. 231–246. CABI Publishing, Wallingford UK.

Macfadyen, S., Gibson, R., Polaszek, A., Morris, R. J., Craze, P. G., Planque, R., Symondson, W. O., and Memmott, J. (2009). Do differences in food web structure between organic and conventional farms affect the ecosystem service of pest control? *Ecology Letter* **12**, 229–238.

Macqueen, K. M., and Milstein, B. (1999). A System Approach to Qualitative Data Management and Analysis. *Field Method* **11**, 27–39.

Madge, D. (2009). "Organic Citrus - A growers' manual." Rural Industries Research and Development Corporation, Publication No. 09/050, p170, Kingston ACT 2604, Australia.

Makokha, M., Odera, H., Maritim, H. K., Okalebo, J. R., and Iruria, D. M. (1999). Farmers' perceptions and adoption of soil management technologies in western Kenya. *African Crop Science Journal* **7**, 549–558.

Malone, S., Herbert, D. A. J., and Pheasant, S. (2004). Determining adoption of integrated pest management practices by grain darmers in Virginia. *Journal of Extension (On-line)* **42**, Article 4RIB6, http://www.joe.org/joe/2004august/rb6.php, (Accessed 15 September 2015).

Maredia, K. M. (2003). Chapter 1: Introduction and Overview. *In* "Integrated pest management in the global arena" (K. M. Maredia, D. Dakouo and D. Mota-Sanchez, eds.), pp. 1–8. CABI Publishing, Wallingford UK.

Maredia, K. M., Dakouo, D., Mota-Sanchez, D., and Raman, K. V. (2003). Chapter 39: Making IPM Successful and Networking Recommendations. *In* "Integrated Pest Management in the Global Arena" (K. M. Maredia, D. Dakouo and D. Mota-Sanchez, eds.), pp. 501–505. CABI Publishing, Wallingford, UK.

Marsh, S. P., and Pannell, D. J. (2000). Agricultural extension policy in Australia: the good, the bad and the misguided. *Australian Journal of Agricultural and Resource Economics* **44**, 605–627.

Marsh, T. L., and Gallardo, K. (2009). Adopting biological control for ornamental crops in greenhouses. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and National Resources* **4**, 1–9.

Mason, M. (2010). Sample Size and Saturation in PhD Studies Using Qualitative Interviews (63 paragraphs). *Forum Qualitative Sozialforschung/Forum: Qualitative Social Research* **11**, 8.

Mauceri, M. (2004). Adoption of Integrated Pest Management Technologies: A Case Study of Potato Farmers in Carchi, Ecuador. M.Sc. Thesis, Virginia Polytechnic Institute and State University Blacksburg, Virginia, USA.

Mazzocco, M. A., Mjelde, J. W., Sonka, S. T., Lamb, P. J., and Hollinger, S. E. (1992). Using Hierarchical Systems Aggregation to Model the Value of Information in Agriculture Systems; An Application for Climate Forcast Information. *Agricultural Systems* **40**, 393–412.

McNamara, K. T., Wetzstein, M. E., and Duouce, G. K. (1991). Factors affecting peanut producer adoption of integrated pest management. *Review of Agricultural Economics* **13**, 129–139.

McNeil, J. N., Cotnoir, P. A., Leroux, T., Laprade, R., and Schwartz, J. L. (2010). A Canadian national survey on the public perception of biological control. *BioControl* **55**, 445–454.

Monk, A. (2012). Organic food and farming in Australia,1301.0, Year Book Australia, 2012, Australian Bureau of Statistics, Canberra, Australia.

Morse, J. G., and Brawner, O. L. (1986). Toxicity of pesticides to *Scirtothrips citri* (Thysanoptera: Thripidae) and implications to resistance management. *Journal of Economic Entomology* **79**, 70.

Morse, S., and Buhler, W. (1997). IPM in developing countries: the danger of an ideal. *Integrated Pest Management Reviews* **2**, 175–185.

Moser, R., Pertot, I., Elad, Y., and Raffaelli, R. (2008). Farmers' attitudes toward the use of biocontrol agents in IPM strawberry production in three countries. *Biological Control* **47**, 125–132.

Murphy, G. D., Furguson, G., Frey, K., Lambert, L., Mann, M., and Matteoni, J. (2002). The use of biological control in Canadian greenhouse crops. *IOBC WPRS Bulletin* **25**, 193–196.

Namey, E., Guest, G., Thairu, L., and Johnson, L. (2008). Data reduction techniques for large qualitative datasets. *In* "Handbook for Team-based Qualitative Research" (G. Guest and K. MacQueen, eds.), pp. 137–161. AltaMira Press Lanham, Maryland,USA.

Neeson, R. (2007). Going Organic, Organic Vegetable Production, A guide to convert to organic production. pp. Publication Number 07/137. Rural Industries Research and Development Corporation (RIRDC), NSW Department of Primary Industries, Yanco, Australia.

New, T. R. (2002). Insects and Pest Management in Australian Agriculture. (M. David, ed.), pp. 346. Oxford University Press, Melbourne, Australia.

Nowak, P. J. (1987). The adoption of conservation technologies: economic and diffusion explanations. *Rural Scociology* **52**, 208–220.

NSW Department of Primary Industries (2012). NSW DPI and fruit industry join forces to develop fruit fly plan. http://www.dpi.nsw.gov.au/aboutus/news/all/2012/fruit-fly-plan (Accessed 14 September 2015).

O'Neil, R. J., and Obrycki, J. J. (2009). Introduction and augmentation of biological control agents. *In* "Integrated Pest Management Concepts, Tactics, Strategies and Case Studies" (E. B. Radcliffe, W. D. Hutchison and R. E. Cancelado, eds.), pp. 107–115. Cambridge University Press, The Edinburgh Building, Cambridge CB2 8RU, UK.

Obrycki, J. J., Lewis, L. C., and Orr, D. B. (1997). Augmentative releases of entomophagous species in annual cropping systems. *Biological Control* **10**, 30–36.

Office of Technology Assessment (1995). Biologically Based Technologies for Pest Control. U.S. Office of Technology Assessment. Congress Government Printing Office, Washington, DC. USA.

Olsen, L., Zalom, F. G., and Adkisson, P. (2003). Integrated Pest Management. *In* "Integrated Pest management in the Global Arena" (K. M. Maredia, D. Dakouo and D. Mota-Sanchez, eds.), pp. 249–271. CABI Publishing, Wallingford, UK.

Oman, J. (2011). Understanding your competition. Small Business BC, Market Research. http://smallbusinessbc.ca/article/understanding-your-competition, (Accessed 14 September 2015).

Onwuegbuzie, A. J., and Leech, N. L. (2005). On becoming a pragmatic researcher: The importance of combining quantitative and qualitative research methodologies *International Journal of Social Research Methodology: Theory and Practice* **8**, 375–387.

Pannell, D. J., Marshall, G. R., Barr, N., Curtis, A., Vanclay, F., and Wilkinson, R. (2006). Understanding and promoting adoption of conservation practices by rural landholders. *Australian Journal of Experimental Agriculture* **46**, 1407–1424.

Papacek, D. (2006). The role of biological control in citrus pest management in Australia. *In* "Proceedings, Fifth California Conference in Biological Control, July 25–27, 2006" (M. S. Hoddle and M. W. Johnson, eds.), pp. 16–23, The Mission Inn, Riverside, California, USA.

Papacek, D., and Smith, D. (1992). Integrated pest management of citrus in Queensland, Australia: Recent developments and current status. *In* "Proceedings of the Seventh International Society of Citriculture Congress, 8–13 March 1992", Vol. 3, pp. 973–977, Acireale, Italy.

Parrella, M. P., Heinz, K. M., and Nunney, L. (1992). Biological control through augmentative releases of natural enemies: a strategy whose time has come. *American Entomologist* **38**, 172–179.

Parsa, S., Morse, S., Bonifacio, A., Chancellor, T. C. B., Condori, B., Crespo-Pérez, V., Hobbs, S. L. A., Kroschel, J., Ba, M. N., Rebaudo, F., Sherwood, S. G., Vanek, S. J., Faye, E., Herrera, M., and Dangles, O. (2014). Obstacles to integrated pest management adoption in developing countries. *Proceedings of the National Academy of Sciences of the United States of America* **111**, 3889–3894.

Penn, S. (1998). The Insectary Business: Our Realities. *In* "California Conference on Biological Control. Innovation in Biological Control Research" (M. S. Hoddle, ed.), pp. 98–99, University of California, Berkeley, USA.

Perovic, D. J., Gurr, G. M., Raman, A., and Nicol, H. I. (2010). Effect of landscape composition and arrangement on biological control agents in a simplified agricultural system: A cost-distance approach. *Biological Control* **52**, 263–270.

Pilkington, L. J., Messelink, G., van Lenteren, J. C., and Le Mottee, K. (2010). "Protected Biological Control" - Biological pest management in the greenhouse industry. *Biological Control* **52** 216–220.

Place, F., and Dewees, P. (1999). Policies and Incentives for the Adoption of Improved Fallows. *Agroforestry Systems* **47**, 323–43.

Pretty, J., and Uphoff, N. (2002). Human Dimensions of Agroecological Development. *In* "Agroecological Innovations: Increasing Food Production with Participatory Development" (N. Uphoff, ed.), pp. 243–50. Earthscan Publications, London, UK.

Primary Industries and Regions SA (2015). Fruit fly quarantine ends in Adelaide's north eastern suburbs. http://pir.sa.gov.au/alerts_news_events/news/biosecurity/fruit_fly/fruit_fly_quarantine_ends_in_adelaides_north_eastern_suburbs, (14 September 2015).

Prokopy, L. S., Floress, K., Klotthor-Weinkauf, D., and Baumgart-Getz, A. (2008). Determinants of agricultural best management practice adoption: Evidence from the literature. *Journal of Soil and Water Conservation* **63**, 300–311.

Rebek, E. J., Schnelle, M. A., and Kelsey, K. D. (2013). Adoption of Integrated Pest Management Practices Among Oklahoma Greenhouse Producers: A Case Study for Experiential Learning. *Journal of Extension* **51**, No. 6, Article # 6RIB4.

Richards, L., and Morse, J. M. (2007). Readme First for a User's Guide to Qualitative Methods. pp. 287. Sage Publications Inc., California, USA.

Ridgway, R. L., and Inscoe, M. N. (1998). Mass-reared natural enemies for pest control: trends and challenges. *In* "Mass-reared Natural Enemies: Application, Regulation, and Needs" (R. L. Ridgway, J. H. Hoffman, M. N. Inscoe and C. S. Glenister, eds.). Entomological Society of America, Lanham, Maryland, USA.

Ridgway, R. L., King, E. G., and Carrillo, J. L. (1977). Augmentation of natural enemies for control of plant pests in the western hemisphere. *In* "Biological Control by Augmentation of Natural Enemies: Insect and Mite Control with Parasites and Predators" (R. L. Ridgeway and S. B. Vinson, eds.), pp. 480. Plenum Press, New York, USA.

Ridgway, R. L., and Vinson, S. B. (1977). "Biological Control by Augmentation of Natural Enemies," Plenum Press, New York.

Risch, S. J. (1987). Agricultural ecology and insect outbreaks. *In* "Insect Outbreaks" (P. Barbosa and J.C.Schultz, eds.), pp. 578. Academic Press, San Diego, USA.

Rogers, E. M. (1983). "Diffussion and Innovation. Third Edition," The Free Press, New York, USA.

Rogers, E. M., and Shoemaker, F. F. (1971). "Communication of Innovations: A Cross-Cultural Approach. 2nd Ed," The Free Press, New York, USA.

Rose, R. (2005). Transcript of Evidence,20, October 2005, Chapter 1 – Parliament of Australia. pp. 5. www.aph.gov.au/.../House_of_representatives_Committees?url (Accessed 24 August 2015).

Rossman, G. B., and Wilson, B. L. (1985). Numbers and words: Combining quantitative and qualitative methods in a single large-scale evaluation study. *Evaluation Review* **9**, 627-643.

Sadati, S. A., Fami, H. S., A. , Asadi, A., and Sadati, S. A. (2010). Farmer's attitude on sustainable agriculture and its determinants: A case study in Behbahan Country of Iran. *Research Journal of Applied Sciences, Engineering and Technology* **2**, 422–427.

Samiee, A., Rezvanfar, A., and Faham, E. (2009). Factors influencing the adoption of integrated pest management (IPM) by wheat growers in Varamin Country, Iran. *African Journal of Agricultural Resaerch* **4**, 491–497.

Sansavini, S. (1997). Integrated fruit production in europe: research and strategies for a sustainable industry. *Scientia Horticulturae* **68**, 25–36.

Schellhorn, N., Renwick, A., and Macfadyen, S. (2013). The real cost of pesticides in Australia's food boom, The Conversation Media Group, Academic rigour, journalistic flair. The Conversation Media Group Ltd, Melbourne, Australia.

Schumacher, S. K., and Marsh, T. L. (2003). Economies of scale in the floriculture industry. *Journal of Agricultural and Applied Economics* **35**, 497–507.

Selvaraj, S., Ganeshamoorthi, P., and Pandiaraj, T. (2013). Potential impacts of recent climate change on biological control agents in agro-ecosystem: A review. *International Journal of Biodiversity and Conservation* **5**, 845–852.

Sette, F., Hawtin, J., and Argus, S. (2011). 2011 National Citrus Plantings Database. pp. 86. Citrus Australia Ltd, Australia.

Shennan, C., Cecchettini, C. L., Goldman, G. B., and Zalom, F. G. (2001). Profiles of California farmers by degree of IPM use as indicated by self-descriptions in a phone survey. *Agriculture, Ecosystems & Environment* **84**, 267–275.

Shojaei, S. H., Hosseini, S. F., Mirdamadi, M., and Zamanizadeh, H. R. (2013). Investigating Barriers to Adoption of Integrated Pest Management Technologies in Iran. *Annals of Biological Resaerch* **4**, 39–42.

Sidibe, A. (2005). Farm-level adoption of soil and water conservationtechniques in northern Burkina Faso. *Agricultural Water Management* **71**, 211–224.

Sigsgaard, L. (2005). Biological control of arthropod pests in outdoor crops- the new challenge. *In* "Proceedings of the International Workshop Implementation of Biocontrol in Practice in Temperate Regions- Present and Near Future". Research Centre, Flakkebjerg, Denmark.

Sivinski, J. (2013). Augmentative biological control: research and methods to help make it work. *CAB International* **8**, 1–11.

Smith, D., Beattie, G. A. C., and Broadley, R. (1997). Citrus Pests and Their Natural Enemies: Integrated Pest Management in Australia. Brisbane: Queensland Department of Primary Industries QL 97001, Australia.

Smith, D., and Papacek, D. F. (1993). Integrated pest manageent in Queensland citrus-recent development. *In* "Pest Control and Sustainable Agriculture." (S. A. Corey, D. J. Dall and W. M. Milne, eds.), pp. 112–115. CSIRO, Canberra, Australia.

Smith R.F., and Huffaker, C. B. (1973). Integrated control strategy in the United States and its practical implementation. *OEPP/EPPO Bulletin* **3**, 31–49.

Smith, R. F. (1974). Origins of integrated control in California, an account of the contributions of Charles W. Woodworth. *Pan-Pacific Entomologist* **4**, 426–40.

Sorati, M., Newman, M., and Hoffmann, A. A. (1996). In breeding and incompatibility in *Trichogramma brassicae:* evidence and implications for quality control. *Entomologia Experimentalis et Applicata* **78**, 283–290.

Speiser, B., Wyss, E., and Maurer, V. (2004). Biological control in organic production: first choice or last option? *In* "An Ecological and Societal Approach to Biological Control" (J. Eilenberg and H. M. T. Hokkannen, eds.), pp. 27–46. Springer Dordrecht, The Netherlands.

Staley, C., and Shockley-Zalabak, P. (1989). Triangulation in gender research: the need for converging methodologies. *In* "Doing research on women's communication: perspectives on theory and method" (K. Carter and C. Spitzack, eds.), pp. 242–261. Ablex, New Jersey, USA.

Stern, V. M., Smith, R. F., van den Bosch, R., and Hagen, K. (1959). The integrated control concept. *Hilgardia* **29**, 81–101.

Stuart, R. J., Barbercheck, M. E., Grewal, P. S., Taylor, R. A. J., and Hoy, C. W. (2006). Population biology of entomopathogenic nematodes: concepts, issues and models. *Biological Control* **38**, 80–102.

Suverkropp, B. P., Bigler, F., and Van Lenteren, J. C. (2009). Dispersal behaviour of *Trichogramma brassicae* in maize fields. *Bulletin of Insect Ecology* **62**, 113–120.

Tabone, E., Bardon, C., and Desneux, N. (2012). Study of dispersal as a selection criterion for Trichogrammatidae for biological control in cauliflower greenhouses. *Acta Horticultaurae* **927**, 227–236.

Taig, L. (2009). Protected cropping. pp. 53. International Specialised Skills Institute Inc., Melbourne, Australia.

Tashakkori, A., and Teddlie, C. (2003). The past and future of mixed methods research: From data triangulation to mixed model designs. *In* "Handbook of mixed methods in social and behavioral resaerch" (A. Tashakkori and C. Teddlie, eds.), pp. 671–702. Sage Publications Thousand Oaks, CA. USA.

Taylor, F. (2013). Agriculture extension though grower groups - a focus of Grain and Graze 2. *Extension Farming Systems Journal, Industry Forum* **9**, 222–226.

Tette, J. P. (1997). New York State Integrated Pest Management Program, New York State Department of Agriculture and Market. pp. 60. Cornell Cooperative and Extension, Cornell University, California, CA, USA.

Thakore, Y. (2006). The Biopesticide Market for Global Agricultural use. *Industrial Biotechnology* **2** 193–208.

Tiwari, K. R., Sitaula, B. K., Nyborg, I. L. P., and Paudel, G. S. (2008). Determinants of Farmers' Adoption of Improved Soil Conservation Technology in a Middle Mountain Watershed of Central Nepal. *Environmental Manageent* **42**, 210–222.

Tracy, E. F. (2014). The Promise of Biological Control for Sustainable Agriculture: a Stakeholder-Based Analysis. *Journal of Science Policy and Governance* **5**, www.sciencepolicyjournal.org (Accessed 20 March 2016).

Trochim, W. (2000). "The Research Methods Knowledge Base, 2nd Edition," Atomic Dog Publishing, Cincinnati, OH, USA.

Trumble, J. T. (1998). IPM: Overcoming Conflicts in Adoption. *Integrated Pest Management Reviews* **3**, 195–207.

Trumble, J. T., and Morse, J. P. (1993). Economics of integrating the predaceous mite *Phytoseiulus persimilis* (Acari: Phytoseiidae) with pesticides in strawberries. *Journal of Economic Entomology* **86**, 879–885.

Truscott, G. (2006). Transcript of Evidence, 10 March. pp. 32. www.aph.gov.au/.../House_of_representatives_Committees?url, (Accessed 24 August 2015).

Uhm, K. B. (2002). Integrated Pest Management, Food & Fertilizer Technology Center for the Asia and Pacific Region. Publication Database, Extension Bulletins, http://www.agnet.org/libray/abstract/eb470.html, (Accessed 24 July 2015).

Unwin, B. (1973). Chemical resistance in populations of Tetranychus utricae Koch (Acarina: Tetranychidae) from apple orchards in N.S.W. Australia. *Australian Journal of Entomology* **12**, 59–67.

Urquhart, P. (1999). IPM and the Citrus Industry in South Africa. *In* "Gatekeeper Series 86, Sustainable Agriculture and Rural Livelihoods Programme, International Institute for Environment and Development", pp. 23. http://pubs.iied.org/pdfs/6338IIED.pdf, (Accessed 27 July 2015), London, UK.

Valentin, R. J. (2003). Economics of Marketing and Technical Support in the Commercial Biological Control Industry. *In* "Proceedings of First International Symposium on Biological control of Arthropods", pp. 51–153, Honolulu, HI, USA.

Van De Vrie, M., McMurtry, J. A., and Huffaker, C. B. (1972). Ecology of tetranychid mites and their natural enemies: a review. III. Biology, ecology and pest status and host–plant relations of Tetranychids. *Hilgardia* **41**, 343–432.

Van Driesche, R. G., and Bellows, T. S. J. (1996). "Biological Control," Chapman and Hall, New York, USA.

Van Driesche, R. G., and Heinz, K. M. (2004). An overview of biological control in protected culture. *In* "Biocontrol in protected culture" (K. M. Heinz, R. G. van Driesche and M. P. Parrella, eds.). Batavia, Ball Publishing, Chicago,USA.

Van Driesche, R. G., Hoddle, M. S., and Center, T. (2008). Control of Pests and Weeds by Natural Enemies: An introduction to biological control. pp. 473. Blackwell Publishing, Oxford, UK.

van Frankenhuyzen, K. (1993). The Challenge of *Bacillus thuringiensis*. *In* "*Basillus thuringiensis*, An Environmental Biopesticide: Theory and Practice" (P. Entwistle, J. S. Cory, M. J. Bailey and S. Higgs, eds.), pp. 1–35. John Wiley, New Work, USA.

van Lenteren, J. C. (1995). Integrated pest management in protected crops. *In* "Integrated Pest Management" (D. Dent, ed.), pp. 311–343. Chapman and Hall, London, UK.

van Lenteren, J. C. (2000a). A greenhouse without pesticides: Fact or fantacy? *Crop Protection* **19**, 375–384.

van Lenteren, J. C. (2000b). Success in Biological Control of Arthropods by Augmentation of Natural Enemies. *In* "Biological Control: Measures of Success" (G. M. Gurr and S. Wratten, eds.), pp. 77–103. Kluwer Academic Publishers, Dordrecht, The Netherlands.

van Lenteren, J. C. (2003a). Commercial availability of biological control agents. *In* "Quality Control and Production of Biological Control Agents: Theory and Testing Procedures" (J. C. van Lentern, ed.), pp. 167–179. CABI Publishing, Wallingford, UK.

van Lenteren, J. C. (2003b). Need for Quality Control of Mass-produced Biological Control Agents. *In* "Quality Control and Production of Biological Control Agents: Theory and Testing Procedures" (J. C. van Lenteren, ed.), pp. 215–224. CABI Publishing, Cambridge, USA.

van Lenteren, J. C. (2006). How not to evaluate augmentative biological control. *Biological Control* **39**, 115–118.

van Lenteren, J. C. (2007). "Internet Book of Biological Control, 4th Edition," www.IOBC-global.org, (Accessed 18 November 2014), Wageningen, The Netherlands.

van Lenteren, J. C. (2012). The state of commercial augmentative biological control: plenty of natural enemies, but a frustrating lack of uptake. *BioControl* **57**, 1–20.

van Lenteren, J. C., Bale, J., Bigler, E., Hokkanen, H. M. T., and Loomans, A. M. (2006). Assessing risks of releasing exotic biological control agents of arthropod pest. *Annual Review of Entomology* **51**, 609–634.

van Lenteren, J. C., and Bueno, V. H. P. (2003). Augmentative biological control of arthropods in Latin America. *BioControl* **48**, 123–139.

van Lenteren, J. C., Hale, A., Klapwijk, J. N., van Schelt, J., and Steinberg, S. (2003). Guidelines for Quality Control of Commercially Produced Natural Enemies. *In* "Quality Control and Production of Biological Control Agents. Theory and Testing Procedures" (J. C. van Lanteren, ed.), pp. 265–303. CABI Publishing, Cambridge, USA.

van Lenteren, J. C., Roskam, M. M., and Timmer, R. (1997). Commercial Mass Production and Pricing of Organisms for Biological Control of Pests in Europe. *Biological Control* **10**, 143–149.

van Lenteren, J. C., and Tommasini, M. G. (2003). Mass Production, Storage, Shipment and Release of Natural Enemies. *In* "Quality Control and Production of Biological Control Agents: Theory and Testing Procedures" (J. C. Van Lenteren, ed.). CABI Publishing, Cambridge, Massachusetts, USA.

van Lenteren, J. C., and Woets, J. V. (1988). Biological and integrated pest control in greenhouses. *Annual Review of Entomology* **33**, 239–269.

van Roermund, H. J. W., van Lenteren, J. C., and Rabbinge, R. (1997). Biological Control of Greenhouse Whitefly with the Parasitoid *Encarsia formosa* on Tomato: An Individual-Based Simulation Approach. *Biological Control* **9**, 25–47.

Vanaclocha, P., Papacek, D., Monzó, C., Verdú, M. J., and Urbaneja, A. (2013). Intra-guild interactions between the parasitoid *Aphytis lingnanensis* and the predator *Chilocorus circumdatus*: Implications for the biological control of armoured scales. *Biological Control* **65**, 169–175.

Varela, L. G., and Bentley, W. J. (2011). Card set. *In* "ISBN–13:978–1–60107–736–3", Vol. 3532, USA.

Wabule, M. N., Ngaruiya, P. N., Kimmins, F. K., and Silverside, P. J. (2004). Registration for biocontrol agents in Kenya. *In* "Proceedings of the Pest Control Products Board/ Kenya Agricultural Research Institute/Department for International Development Crop Protection Programme Workshop", pp. 230. KARI/PCPCC, Natural Resources International Limited, Nakuru, Kenya.

Walker, J. L. (2012). Research column. The Use of Saturation in Qualitative Research. *Canadian Journal of Cardiovascular Nursing* **22**, 37–41.

Waller, B. E., Hoy, C. W., Henderson, J. L., Stinner, B., and Welty, C. (1998). Matching innovations with potential users, a case study of potato IPM practices. *Agriculture, Ecosystems and Environment* **70**, 203–215.

Warner, K. D. (2007). "Agroecology in Action: Extending Alternative Agriculture Through Social Networks," MIT Press, Cambridge, MA, USA.

Warner, K. D., and Getz, C. (2008). A socio-economic analysis of the North American commercial natural enemy industry and implications for augmentative biological control. *Biological Control* **45**, 1–10.

Waterhouse, D. F., and Sands, D. P. E. (2001). Classical biological control of arthropods in Australia. ACIAR Monograph No.77. pp. 560. Australian Centre for International Agricultural Research (ACIAR), Canberra, Australia.

Wawrzynski, R. P., Ascerno, M. E., and McDonough, M. J. (2001). A Survey of Biological Control Users in Midwest Greenhouse Operations. *American Entomologist* **47**, 228–234.

Wearing, C. H. (1988). Evaluating the IPM implementation process. *Annual Review of Entomology* **33**, 17–38.

Whiting, L. S. (2008). Semi-structured interviews: guidance for novice researchers. *Nursing Standared* **22**, 35–40.

Williams, D. (2000). "National guidelines for Integrated Fruit Production in Australia: apples." Horticultural Research and Development Corporation final report series, Sydney, Australia.

Williams, D. G., and Il'ichev, A. L. (2003). "Integrated pest management in Australia," CABI Publishing, Wallingford UK.

Williamson, S. (1998). Understanding natural enemies; a review of training and information in the practical use of biological control. *Biocontrol News and Information* **19**, 117–125.

Williamson, S., Little, A., Ali, M. A., Kiman, M., Meir, C., and Oruko, L. (2003). Aspects of cotton and vegetable farmers' pest management decision-making in India and Kenya *Internation Journal of Pest Management* **49**, 187–198.

Wissinger, S. (1997). Cyclic colonization in predictably ephemeral habitats: a template for biological control in annual crop systems *Biological Control* **10**, 4–15.

Woods, M. (2011). Interviewing for research and analysing qualitative data: An overview. School of Health and Social Services, Massey University, New Zealand.

Wratten, S. D., and Gurr, G. M. (2000). Synthesis: The Future Success of Biological Control. *In* "Biological Control: Measures of Success. " (G. M. Gurr and S. Wratten, eds.), pp. 405–416. Kluwer Academic Publishers., Dordrecht, The Netherlands.

www.biologicalservices.com.au/history.html (Accessed 1 May 2015).

www.bioresources.com.au/MacTrix/index.html (Accessed 11 March 2011).

www.en.worldstat.info/Europe/Land Accessed 6 February 2016.

www.goodbugs.org.au (Access 25 March 2011).

www.goodbugs.org.au (Accessed 1 May 2015).

www.ipmtechnologies.com.au (Accessed 10 march 2010).

www.ncipm.org.in/ ICAR - National Centre for Integrated Pest Management.

www.nfer.ac.uk/schools/developing-young-researchers/how-to-present-your-results.cfm (Accessed 31 July 2015).

www.oranges.com.au/industry/ (Accessed 21 September 2015).

Yano, E. (1993). Prospects for biological control in protected crops in Japan. *Bulletin OILB/SROP* **16**, 189–192.

Yano, E. (2004). Recent Development of Biological Control and IPM in Greenhouses in Japan. *Journal of Asia-Pacific Entomology* **7**, 5–11.

Zalucki, M. P., Adamson, D., and Furlong, M. J. (2009). The future of IPM: whither or wither? *Australian Journal of Entomology* **48**, 85–96.

Zehnder, G., Gurr, G. M., Kuhne, S., Wade, M. R., Wratten, S. D., and Wyss, E. (2007). Arthropod Pest Management in Organic Crops. *Annual Review of Entomology* **52**, 57–80.

www.wadesonip.com.au/patent-attorney-services/patents/patent-costs/- Access: 7 February, 2016.

Appendices

Appendix 1: Cover letter for the Australian insectary owners' interviews.

THE UNIVERSITY OF SYDNEY

ABN 15 211 513 464

CHIEF INVESTIGATOR'S/SUPERVISOR'S NAME
Dr Sarah Mansfield
Senior Lecturer in Entomology

Faculty of Agriculture and Environment
Room 404, Biomedical Building C81
AustralianTechnology Park, Eveligh, The University of Sydney NSW 2015,
AUSTRALIA
Telephone: +61 2 8627 1049,
Facsimile:+61 2 8627 1099,
Email: sarah.mansfield@sydney.edu.au
Web: http://www.usyd.edu.au/

Letter for Interview with insectary owners

Subject: A Comprehensive Study of the Australian Commercial Insectary Industry and it's Implications for Augmentative Biological Control- Stage 1.

Dear Participant,

The study is being conducted by Mahmuda Begum (Student) and will form the basis for the degree of PhD at The University of Sydney under the supervision of Dr Sarah Mansfield (Principal supervisor) and Mr Peter Ampt (Associate supervisor). This project aims to identify factors which influence the behaviour of individuals and institutions engaged in commercial natural enemy production, release and distribution. This project will also investigate citrus growers' attitudes to or perceptions of the use of augmentative biological control.

All aspects of the study, including results, will be strictly confidential. Data will be analysed in an aggregated form. Any publication of results will have participants de-identified. However, your responses are important to understand the unfulfilled potential in augmentative biological control in Australia.

I will send you a participant information statement and participant consent form soon and arrange a suitable time to conduct an interview with you in your office or by phone. I hope you will be able to find time in your busy schedule to undertake the interview. Your participation in this interview is most appreciated and if you have any questions or enquires feel free to contact me by email at mahmuda.begum@sydney.edu.au or by Tel: 02 8627 1064.

Yours faithfully,

Mahmuda Begum (PhD Student)
Faculty of Agriculture and Environment
The University of Sydney

Any person with concerns or complaints about the conduct of a research study can contact the Deputy Manager, Human Ethics Administration, University of Sydney on +61 2 8627 8176 (Telephone); +61 2 8627 8177 (Facsimile) or ro.humanethics@sydney.edu.au (Email).

Appendix 2: Cover letter for citrus pest management researchers' interviews.

THE UNIVERSITY OF SYDNEY

ABN 15 211 513 464

CHIEF INVESTIGATOR'S/SUPERVISOR'S NAME
Dr Sarah Mansfield
Senior Lecturer in Entomology

Faculty of Agriculture and Environment
Room 404, Biomedical Building C81
AustralianTechnology Park, Eveligh, The
University of Sydney NSW 2015,
AUSTRALIA
Telephone: +61 2 8627 1049,
Facsimile:+61 2 8627 1099,
Email: sarah.mansfield@sydney.edu.au
Web: http://www.usyd.edu.au/

Letter for Interview with Researchers

Subject: The University of Sydney research about the Australian Insectary Industry and it's implication for augmentative biological control- Stage II.

Dear Participant,

The University of Sydney's researchers invite you to participate in the interviews on Australian Insectary Industry and its implication for augmentative biological control which is one of the components of this project. The study is being conducted by Mahmuda Begum (Student) and will form the basis for the degree of PhD at The University of Sydney under the supervision of Dr Sarah Mansfield (Principal supervisor) and Mr Peter Ampt (Associate supervisor). This project aims to identify factors which influence the behaviour of individuals and institutions engaged in commercial natural enemy production, release and distribution. This project will also investigate citrus growers' attitudes to or perceptions of the use of augmentative biological control and researchers' perceptions about the expansion of the commercial insectary industry and its implications for augmentative biological control in Australia.

All aspects of the study, including results, will be strictly confidential. Data will be analysed in an aggregated form. Any publication of results will have participants de-identified. However, your responses are important to understand the unfulfilled potential of augmentative biological control in Australia.

I will send you a participant information statement and participant consent form soon and arrange a suitable time to conduct an interview with you in your office or by phone. I hope you will be able to find time in your busy schedule to undertake the interview.

Your participation in this interview is most appreciated and if you have any questions or enquires feel free to contact me by email at mahmuda.begum@sydney.edu.au or by Tel: 02 86271064.

Yours faithfully,
Mahmuda Begum (PhD Student)
Faculty of Agriculture and Environment
The University of Sydney,

Any person with concerns or complaints about the conduct of a research study can contact the Deputy Manager, Human Ethics Administration, University of Sydney on +61 2 8627 8176 (Telephone); +61 2 8627 8177 (Facsimile) or ro.humanethics@sydney.edu.au(Email).

Appendix 3: Cover letter for citrus growers' interviews.

ABN 15 211 513 464	Faculty of Agriculture and Environment
CHIEF INVESTIGATOR'S/SUPERVISOR'S NAME **Dr Sarah Mansfield** **Senior Lecturer in Entomology**	Room 404, Biomedical Building C81 AustralianTechnology Park, Eveligh, The University of Sydney NSW 2015, AUSTRALIA Telephone: +61 2 8627 1049, Facsimile: +61 2 8627 1099, Email: sarah.mansfield@sydney.edu.au Web: http://www.usyd.edu.au/

Letter for Interview with Citrus Growers

Subject: A Comprehensive Study of the Australian Commercial Insectary Industry and it's Implications for Augmentative Biological Control –Stage 1.

Dear Participant,

The study is being conducted by Mahmuda Begum (Student) and will form the basis for the degree of PhD at The University of Sydney under the supervision of Dr Sarah Mansfield (Principal supervisor), and Mr Peter Ampt (Associate supervisor). This project aims to identify factors which influence the behaviour of individuals and institutions engaged in commercial natural enemy production, release and distribution. This project will also investigate citrus growers' attitudes to or perceptions of the use of augmentative biological control.

All aspects of the study, including results, will be strictly confidential. Data will be analysed in an aggregated form. Any publication of results will have participants de-identified. However, your responses are important to understand the unfulfilled potential in augmentative biological control in Australia.

I will send you a participant information statement and participant consent form soon and arrange a suitable time to conduct an interview with you by telephone. I hope you will be able to find time in your busy schedule to undertake the interview.

Your participation in this interview is most appreciated and if you have any questions or enquires feel free to contact me by email at mahmuda.begum@sydney.edu.au or by Tel: 02 86271064.

Yours faithfully,
Mahmuda Begum (PhD Student)
Faculty of Agriculture and Environment
The University of Sydney

Any person with concerns or complaints about the conduct of a research study can contact the Deputy Manager, Human Ethics Administration, University of Sydney on +61 2 8627 8176 (Telephone); +61 2 8627 8177 (Facsimile) or ro.humanethics@sydney.edu.au (Email).

Appendix 4: Survey cover letter published in the citrus magazine "Australian Citrus News" volume 89, June/July 2012.

Letter for Citrus Growers' Survey

Subject: Invitation to participate in the Australian Citrus Growers' Survey 2012.

Dear Grower,

The University of Sydney's researchers invite you to participate in the citrus growers' survey 2012 which is one of the components of this project-

A Comprehensive Study of the Australian Commercial Insectary Industry and its Implications for Augmentative Biological Control.

As you may know, Australian citrus growers face big challenges in exporting their products due to the maximum residue limits (MRLs) set by importing countries. Growers must ensure they comply with the relevant MRLs of the importing country. This is a valuable component of marketing success. Integrated Pest Management (IPM) is an alternative to conventional pest control that can reduce the use of pesticides, and augmentative biological control is one of the important components of IPM. However it is not clear how augmentative biological controls are currently being used for pest management. Increasing the use of biological control agents will require a greater understanding of the perceptions of citrus growers towards them.

Therefore the study **(A Comprehensive Study of the Australian Commercial Insectary Industry and its Implications for Augmentative Biological Control)** is being undertaken. This study will form the basis for my PhD at The University of Sydney under the supervision of Dr Sarah Mansfield (Senior Lecturer) and Mr Peter Ampt (Lecturer).

As a citrus grower, your participation in this survey is most appreciated because of your direct experience and knowledge. A questionnaire, which can be found on line at the link cited below, is about several aspects of managing your citrus orchard. All aspects of the study, including results, will be strictly confidential. Data will be analysed in an aggregated form and individual participants will not be identifiable in any publications.

This online survey takes approximately 15–20 minutes to complete. To complete the Australian Insectary Industry Study-Stage 2 please follow this link below;

http://www.surveymonkey.com/s/JCJGZYD

Thank you for your time to undertake this important survey. If you have any questions or enquire please feel free to contact me by email at mahmuda.begum@sydney.edu.au or by Tel: 02 86271064.

Yours faithfully,
Mahmuda Begum (PhD Student)
Faculty of Agriculture and Environment
The University of Sydney

Appendix 5: Handout was distributed with the Australian Citrus News (Volume 90 August / September 2012) for citrus growers' survey participation (2300 copies).

THE UNIVERSITY OF SYDNEY

ABN 15 211 513 464

Faculty of Agriculture and Environment

CHIEF INVESTIGATOR'S/SUPERVISOR'S NAME
Dr Sarah Mansfield
Senior Lecturer in Entomology

Room 404, Biomedical Building C81
AustralianTechnology Park, Eveligh, The University of Sydney NSW 2015, AUSTRALIA
Telephone: +61 2 8627 1049,
Facsimile:+61 2 8627 1099,
Email: sarah.mansfield@sydney.edu.au
Web: http://www.usyd.edu.au/

Dear citrus grower

6 September 2012

How do you manage citrus pests?

Can we please have about 20 minutes of your time to complete an online survey questionnaire? We are keen to learn about how you manage pests in your citrus orchards. The information will help us to understand the range of current pest management practices, and to assess the potential for an expansion of biological control methods for citrus pests. The results will help us to develop recommendations for citrus growers, the insectary industry, researchers and other decision makers. Through this work you should receive better and more targeted information about pest management.

Our research has already indicated that there could be big benefits from increased use of augmentative biological control methods but it is crucial for us to understand, from an orchardist's point-of-view, whether these methods are realistic, practical and economical. To do that, we need many people to complete the survey to be sure that we are getting an accurate picture. We need participation from a wide range of growers, with a wide range of pest management strategies. Please complete this survey if you are the person who makes the pest management decisions for your citrus orchards. Otherwise, please pass this invitation to the person who makes the pest management decisions for your citrus orchards.

All aspects of the study will be strictly confidential and individual participants will not be identifiable in any publications. Your participation is entirely voluntary; however, the more citrus growers that complete the survey, the more representative the data will be and the greater the potential impact of the findings. This project is being undertaken by Mahmuda Begum (PhD student) under the supervision of Dr Sarah Mansfield (Senior Lecturer) and Mr Peter Ampt (Lecturer) from the Faculty of Agriculture and Environment, at the University of Sydney.

This survey will take between 15 to 20 minutes to complete depending on which questions are relevant to you. You can access the survey by typing the following address into your web browser:

http://www.surveymonkey.com/s/JCJGZYD

Alternatively, you can contact me by email: mahmuda.begum@sydney.edu.au or by Tel: 02 8627 1099.

We can then arrange the most convenient way for you to complete the survey. We would like to thank those citrus growers who already completed the online questionnaire and also thanks to the citrus growers who participated in the interviews.

Kind regards,
Mahmuda Begum (PhD Student)
Faculty of Agriculture and Environment
The University of Sydney

Appendix 6: Cover letter (email) for a summary results report feedback.

Dr Sarah Mansfield
Adjunct Senior Lecturer
Faculty of Agriculture and Environment
The University of Sydney
Email: sarah.mansfield@sydney.edu.au

Subject: A comprehensive study of the Australian commercial insectary industry and its implications for augmentative biological control.

Dear Participant,

During 2011–2013, I conducted 27 face-to-face and telephone interviews with insectary owners, citrus pest management researchers and citrus growers. A national survey was also conducted with the citrus growers during 2012–2013. I relished the opportunity to meet with all of you and to learn about your experiences and perceptions.

The purpose of this report is to get your feedback to finalise the results and recommendations of this research. I would greatly appreciate your thoughts on my findings however, the provision of any comments on this report is completely voluntary. You are not under any obligation to consent to make any comments and your responses will be kept anonymous.

I hope you find this report useful and would appreciate your feedback within two weeks by email or letter or fax. Please do not circulate or use this report at this stage because it is not complete yet. I will publish my findings more widely after the research has been finalised. Thank you very much for giving me your time and participation in this project.

Kind regards,

Mahmuda Begum
(PhD Student)
Faculty of Agriculture and Environment
The University of Sydney, NSW 2015, Australia
Tel: 02 8627 1064,
Email: mahmuda.begum@sydney.edu.au

Appendix 7: Interview pro-forma for insectary owners.

This interview pro forma is developed for a targeted audience of Australian insectary companies' owner/managers.

A. General information

-How did you first get involved in this insectary industry? How did you get to where you are now? What difficulties did you face? How did you overcome these difficulties? What help did you get along the way?

-How did you make this decision to establish this insectary? What is your own background?

-Is location important? Why did you choose this location for this insectary?

-What are you hoping to achieve through your insectary business? Do you have any specific goals or objectives?

B. Products/ services

-Could you please describe your major products/services? How has your product list changed over the the years?

-Did you bring new species to the market?

-Where do you get your products from? Do you rear the products on site?

-Which product is your best seller? Are you willing to provide details of your sales activity by product volume?

C. Customers

-Who are your most important customers? Can you describe how your company aims to meet their needs?

-What percentage of your reared biological control agents are sold to agriculture and other areas of pest control? Here agriculture includes- field crops, protected area crops and animal agriculture.

-Do you ship any of your products to customers outside Australia?

-Can you tell me the size of your customer lists either in total numbers or by percentage and by industry segment?

-For which pests do your customers use your products?

-During the last ten years has your customer list been increasing or decreasing?

-What sorts of factors do you think influence your customers to switch from conventional control (broad-spectrum pesticides) to IPM?

-How do you evaluate those factors? Is this reflected on your sale activity, financial (Profit, expenses etc) customer survey, input costs or others?

-Of your customers, approximately how many hectares of agricultural and other areas use biological control agents?

-Do you use specific marketing strategies to promote the sale of biological control agents?

D. Company at present

-How much did it cost to set up your insectary company?

-How many full-time and part-time employees work at your insectary as full-time equivalents?

-During the last ten years, what are your total gross sales per year? If you cannot tell me then can can you tell me the range please?

-How do your sales compare to your costs?

-What factors do you think favour augmentative biological control or leads to increased sales of biological control agents?

-Do you think GM crops (including Bt crops) are having an impact on your business? If so then how do you evaluate that?

-What are the main biological barriers that you have encountered during production of biological control agents and their distribution?

-Product quality and consumer perception of quality are critically important issues. How can you maintain product quality as well as handle your consumer's perception of product quality?

-Does quality management comply with any national or international standards such as IOBC/EC guidelines (International Organization for Biological Control/European Community)?

-To maintain the quality of biological control agents do you work regularly with any university entomologists/researchers?

-What other services do you offer to your customers excluding biological control agents?

-Are you member of any of the International Biocontrol Associations such as-

a) IBMA (International Biocontrol Manufacturers Association),

b) IOBC (International Organization for Biological Control)

c) ANBP (Association of Natural Biocontrol Producers)?

E. Company in future

-How optimistic are you about your company's future?

-Tell me your future research?

-What critical decisions do you face in the near future?

F. The Australian industry as a whole.

-What factors affect the expansion of the Australian commercial insectary industry?

-What opportunities exist for public agency policies or initiatives to make commercial natural enemies or biological control agents a more feasible alternative to chemical pesticides?

-Do you think that current rules and regulations have a large impact on the expansion of the Australian commercial insectary industry?

-What is your opinion about tandem use of selective pesticides and biological control agents in IPM?

Appendix 8: Interview pro-forma for citrus pest management researchers.

A. General information

-How long have you been doing research?

-Some researchers claim augmentative biological control is poor or valueless. What is your opinion?

-Have you done any research in collaboration with a commercial insectary company? Would you consider doing such research?

B. Integrated Pest Management

- How do you define IPM?
- Sometimes farmers use only a few practices such as monitoring tools, baiting traps and chemicals. Do you think such growers are practicing IPM?
- Which factors do you think influence farmers to switch from conventional control methods (broad-spectrum pesticides) to IPM?
- What is your opinion about tandem use of selective pesticides and biological control agents in IPM?
- Public are end users so do you think need to increase public awareness to implement IPM? Please specify.

C. Augmentative Biological Control

- Some researchers claim naturally occurring biological control agents are enough to control the pests. I am interested to know your opinion.
- Do you think some factors favour augmentative biological control or lead to increased natural enemies sales? I am interested to know your opinion.
- Why do some farmers not use biological control agents? Please specify.
- Do you think that the state of the commercial insectary industry strongly influences grower uptake of augmentative biological control? Please specify.

D. Australian Insectary Industry

- What kind of factors affects the expansion of the Australian commercial insectary industry? Do you think economic, social, political or any other factors? Please specify.
- What opportunities exist for public agency policies or initiatives to make commercial natural enemies a more feasible alternative to chemical pesticides? Please specify.
- Do you think that current rules and regulations have a large impact on the expansion of the Australian commercial insectary industry?
- Quality issues are important for biological control agents. Do you think that commercial insectary owners need to work with researchers to maintain the quality of biocontrol products?
- Do you think GM crops (including Bt crops) are having an impact on the commercial insectary? Please specify.

Appendix 9: Interview pro-forma for citrus growers.

This interview pro forma is developed for a targeted audience of citrus growers who may be users or non-users of biological control agents' on their farm for pest management.

A. General information

- How long have you been managing this farm?
- Are you owner of this farm?
- Have you ever heard about biological control?
- Which approach have you considered using on your farm for plant protection? Conventional (Broad-Spectrum pesticides) or IPM?
- Do you currently use biological control agents on your farm?

B. Economic factors

- What's the size of the farm?
- Approximately, how much do you spend on biological control agents or pesticides purchases each year?
- Is this farm your main source of income?
- During the last 5 years, have you been sick as a result of pesticide use?
- How many full-time and part-time employees work on your farm?

C. Technology characteristics

- Which biological control agents are you familiar with? Please list all of these.
- What are the biological control agents you use most commonly, and for which crops? For which pests do you use biological control agents?
- Do you need any training or others before using biological control agents in your farm? Please specify.
- What are the main problems you have encountered in your use of biological control agents?
- Do you encounter any difficulties when you use biological control agents and pesticides together?
- How soon did you apply pesticides after the release of biological control agents?
- Please list your most successful biological control experience.

D. Growers' perception

- What are, in your opinion, the main features of biological control agents that distinguish them from conventional (chemical) tools for plant protection?
- Do you trust the efficacy of biological control agents? Please specify.
- What are the reasons you are using or not using biological control agents on your farm?
- What do you think about using biological control agents are profitable or risky decision?
- Do you think biological control agents cost more than chemical pesticides? Please specify.

E. Institutional factors

- What are your sources of information on the topic of pest management? Workshops, field days, pamphlets, other farmers or other sources?
- Do you get any consultation or other help from government or any other organisations about pest management on your farm?
- What could convince you to use biological control agents or pesticides?

F. Participants' characteristics

- Which age group you are belong to?
  - I. 20-29
  - II. 30-39
  - III. 40-49
  - IV. 50-59
  - V. 60 and over
- What is the highest level of education have you completed?
  - I. Primary
  - II. Secondary
  - III. College
  - IV. University
  - V. Others
- In what state is your farm located?
- Please specify your sex. (Male or Female)
- How many members (excluding you) in your family and how many members working on your farm?

Appendix 10: Survey questionnaire for citrus growers.

The original questionnaire was coded (bold and in bracket) for analysis of participants responses in SPSS software. Code was used such as A for Section I and B for Section II. Each question was coded such as A1, A2, B8, and F34. Question statement variables were coded such as A1 1, B8 1, and F34 1. The codded questionnaire or code book is below:

Survey questionnaire

Section I: Participants' characteristics (Please tick or write responses in appropriate boxes). (**Code: A)**

1. What is your role on the citrus orchards? **(Code: A 1)**

Owner	☐ **(Code: A1 1)**
Manager	☐ **(Code: A1 2)**
Others	☐ **(Code: A1 3)**

Other (please specify)

2. For how many years have you been managing citrus orchards? **(Code: A2)**

3. What is the highest level of education you have completed? **(Code: A3)**

Primary	☐ **(Code: A3 1)**
Secondary	☐ **(Code: A3 2)**
TAFE/Technical /Agricultural college	☐ **(Code: A3 3)**
University	☐ **(Code: A3 4)**
Others	☐ **(Code: A3 5)**

Education relevant to citrus growing

4. To which age group do you belong? **(Code: A 4)**

20-24 years	☐ (**Code: A4 1)**
25-29 years	☐ **(Code: A4 2)**
30-34 years	☐ **(Code: A4 3)**
35-39 years	☐ **(Code: A4 4)**
40-44 years	☐ **(Code: A4 5)**
45-49 years	☐ **(Code: A4 6)**
50-54 years	☐ **(Code: A4 7)**
55-59 years	☐ **(Code: A4 8)**
60-64 years	☐ **(Code: A4 9)**
65 and over years	☐ **(Code: A4 10)**

5. Are you? **(Code: A5)**

Male	☐..**(Code: A5 1)**
Female	☐..**(Code: A5 2)**

6. How many people work on your citrus orchards? If you employ people part-time, please estimate how many full-time people is equivalent to this. **(Code: A6)**

Less than one person full-time	☐ **(Code: A6 1)**
1-5 people full-time	☐ **(Code: A6 2)**
6-10 people full-time	☐ **(Code: A6 3)**
11-20 people full-time	☐ **(Code: A6 4)**
More than 20 people full-time	☐ **(Code: A6 5)**

7. In which state is your citrus orchard located? **(Code: A7)**

ACT	☐	**(Code: A7 1)**
NSW	☐	**(Code: A7 2)**
NT	☐	**(Code: A7 3)**
QLD	☐	**(Code: A7 4)**
SA	☐	**(Code: A7 5)**
TAS	☐	**(Code: A7 6)**
VIC	☐	**(Code: A7 7)**
WA	☐	**(Code: A7 8)**

Section II: Economic factors (Please tick or write responses in appropriate Boxes) **(Code: B).**

8. How many hectares do you have under citrus orchards? **(Code: B8)**

Less than 10 ha	☐	**(Code: B8 1)**
10-20 ha	☐	**(Code: B8 2)**
20-30 ha	☐	**(Code: B8 3)**
30-40ha	☐	**(Code: B8 4)**
More than 40 ha	☐	**(Code: B8 5)**

9. What is the average gross value per year of your citrus production? **(Code: B9)**

$100,000- 200,000	☐	**(Code: B9 1)**
$201,000- 300,000	☐	**(Code: B9 2)**
$301,000- 400,000	☐	**(Code: B9 3)**
$401,000- 500,000	☐	**(Code: B9 4)**
$501,000- 600,000	☐	**(Code: B9 5)**
$601,000- 700,000	☐	**(Code: B9 6)**
$701,000- 800,000	☐	**(Code: B9 7)**
More than $800,000	☐	**(Code: B9 8)**

10. On average, approximately how much do you spend on pest management in your citrus orchards each year? **(Code: B10)**

Biological control agents		**(Code: B10 1)**
Insecticides		**(Code: B10 2)**
Fungicides		**(Code: B10 3)**
Acaricides or Miticides		**(Code: B10 4)**
Herbicides		**(Code: B10 5)**
Bt (i.e., Dipel, Biobit, Condor, etc.)		**(Code: B10 6)**
Oil (Horticultural/Mineral oils)		**(Code: B10 7)**
Consultants		**(Code: B10 8)**
Monitoring		**(Code: B10 9)**
Others		**(Code: B10 10)**

11. What level of crop losses do you usually incur each year and what level is acceptable to you? **(Code: B11)**

	Less than 5% **(1)**	5%-10% **(2)**	11%-15% **(3)**	16%-20% **(4)**	More than 20% **(5)**	
1. Crop losses usually incur each year	☐	☐	☐	☐	☐	**(Code: B11 1)**
2. Crop losses acceptable to me	☐	☐	☐	☐	☐	**(Code: B11 2)**

Section III: General information about citrus farm (Please tick or write responses in appropriate boxes). **(Code: C)**

12. What percentage of the crop is in oranges, mandarins, lemons, limes and grapefruits? **(Code: C12)**

	N/A **(1)**	1%-25% **(2)**	26%-50% **(3)**	51%-75% **(4)**	76%-100% **(5)**	
Oranges	☐	☐	☐	☐	☐	**(Code: C12 1)**
Mandarins	☐	☐	☐	☐	☐	**(Code: C12 2)**
Lemons	☐	☐	☐	☐	☐	**(Code: C12 3)**
Limes	☐	☐	☐	☐	☐	**(Code: C12 4)**
Grapefruits	☐	☐	☐	☐	☐	**(Code: C12 5)**
Others	☐	☐	☐	☐	☐	**(Code: C12 6)**

Others (please specify)

13. What percentage of the whole crop goes to the fresh or juice market? **(Code: C13)**

	N/A **(1)**	1%-25% **(2)**	26%-50% **(3)**	51%-75% **(4)**	76%-100% **(5)**	
Fresh market	☐	☐	☐	☐	☐	**(Code: C13 1)**
Juice market	☐	☐	☐	☐	☐	**(Code: C13 2)**

14. Do you intercrop citrus with other crops? **(Code: C14)**

No ☐ **(1)** (please go to the next Question)

Yes ☐ **(2)**

If yes, which crop do you intercrop with citrus?

15. Do you use any of the following cover crops to maintain your citrus orchard floor? **(Code: C15)**

	No **(1)**	Yes **(2)**	
Orchard floor covered with Clovers	☐	☐	**(Code: C15 1)**
Orchard floor covered with Broad Beans	☐	☐	**(Code: C15 2)**
Orchard floor covered with Grasses	☐	☐	**(Code: C15 3)**
Orchard floor is kept bare	☐	☐	**(Code: C15 4)**
Others	☐	☐	**(Code: C15 5)**

Others (please specify)

16. Answer this question only if you use IPM. If not please go to the next question. Which sort of IPM tools do you use in your citrus orchards? (Tick all that apply) **(Code: C16)**

	No **(1)**	Yes **(2)**	
I use cultural practices such as crop rotation, sanitation etc	☐	☐	**(Code: C16 1)**
I use conservation biological control such as conserving and encouraging beneficial insects	☐	☐	**(Code: C15 2)**
I use chemical control	☐	☐	**(Code: C15 3)**
I use augmentative biological control	☐	☐	**(Code: C15 4)**
I use monitoring	☐	☐	**(Code: C15 5)**
I use insect traps	☐	☐	**(Code: C15 5)**
Others	☐	☐	**(Code: C15 6)**

Others (please use specify)

17. Who makes the decision to spray chemicals or release biological control agents on your citrus orchards? **(Code: C17)**

Owner ☐ **(Code: C17 1)**
Manager ☐ **(Code: C17 2)**
Consultant ☐ **(Code: C17 3)**
Owner and manager ☐ **(Code: C17 4)**
Owner and consultant ☐ **(Code: C17 5)**
Manager and consultant ☐ **(Code: C17 6)**
Others ☐ **(Code: C17 7)**
Others (please specify)

18. Do you follow the economic or damage thresholds when you decide to spray chemicals or release biological control agents? **(Code: C18)**
No ☐ **(Code: C18 1)**
Yes ☐ **(Code: C18 2)**
Don't Know ☐ **(Code: C18 3)**

19. How do you measure the economic or damage thresholds? **(Code: C19)**

20. Answer this question only if you use pesticides (i.e., insecticides, acaricides or miticides and fungicides). If not please go to the next question. **(Code: C20)**

Please choose a pesticide that you use, what you use it for and how often you use it. Repeat for each of the pesticides you regularly use.

Name of pesticide (Code: C20 1)	**Name of pest (Code: C20 2)**	**Name of disease (Code: C20 3)**	**No. ofsprays /year (Code: C20 4)**
1.Ambush……☐**(1)**	N/A……………………☐**(1)**	N/A ………………….☐**(1)**	1…☐ **(1)**
2.Chlorpyrifos (eg.Lorsban)…☐**(2)**	Ants…………………...☐**(2)**	Canker disease………..☐**(2)**	2…☐ **(2)**
3.Confidor….. .☐**(3)**	Asian psyllids................☐**(3)**	Fungal scab disease….☐**(3)**	3…☐ **(3)**
4.Diazinon….. .☐**(4)**	Black flies…..................☐**(4)**	Fungal spot disease. ...☐(4)	4…☐ **(4)**
5.Fipronil…… .☐**(5)**	Black scales..........…....☐**(5)**	Gummosis fungal Disease ………………………...☐(5)	5…☐ **(5)**
6. Imidan……...☐**(6)**	Broad Mites…………...☐**(6)**	Melanos fungaldisease☐**(6)**	6…☐ **(6)**
7.Methidathion (eg.Supracide). ☐**(7)**	Brown aphids................☐**(7)**	Root rot fungal disease……………….☐**(7)**	7…☐ **(7)**
8.Movento……☐**(8)**	Bud mites…...................☐**(8)**	Others……….............☐**(8)**	8…☐ **(8)**
9.Petroleumoils☐**(9)**	California red scales…...☐**(9)**		9…☐ **(9)**
10.Pyrethrum...☐**(10)**	Chinese rose beetle…….☐**(10)**		10....☐ **(10)**
11.SharpFloor..☐**(11)**	Katydids……………….☐**(11)**		
12.Spinosad (eg. Success)……..☐**(12)**	Kelly's thrips…………☐**(12)**		
13.Rogor…….☐**(13)**	Leaf miners……………☐**(13)**		
14.Others……☐**(14)**	Locusts………………....☐**(14)**		
	Light brown apple moth☐**(15)**		
	Mediterranean fruit flies.☐**(16)**		
	Oriental fruit flies……...☐**(17)**		
	Red spider mites………..☐**(18)**		
	White flies……...............☐**(19)**		
	Others…………………...☐**(20)**		

Others (please specify)

21. Answer this question only if you use biological control agents in your citrus orchards. If not please go to the next question. **(Code: C21)**

Please choose a biological control agent that has used what you used it for and how often you use it. Repeat for each of the biological control agents you regularly use. Also please indicate if you are currently using it, and if not, when you last used it.

Name of biological control agent (Code: C21 1)	**Name of citrus variety (Code: C21 2)**	**Name of pest (Code C21 3)**	**Name of disease (Code: C21 4)**	**Using currently (Code: C21 5)**	**Last used (Code: C21 6)**
1.*Aphidius colemani* (Aphidparasitoid)……☐**(1)**	Bahianinha oranges ….☐**(1)**	N/A….☐**(1)**	N/A.........☐**(1)**	No **(1)** Yes **(2)**	6-10 years ago…☐**(1)**
2. *Aphelinus abdominalis* (Aphid parasitoid)…..☐**(2)**	Leng oranges ....☐**(2)**	Ants....☐**(2)**	Cankerdisease ……......☐**(2)**		11-15 years ago…☐**(2)**
3. *Aphytis melinus* (Red scales parasitoid)…….☐**(3)**	Navels oranges….☐**(3)**	Asian syllids..☐**(3)**	Fungal scab Disease..☐**(3)**		16-20 years ago…☐**(3)**
4. *Aphytis lingnanensis* (Red scale parasitoid)☐**(4)**	Navalina oranges….☐**(4)**	Black flies….☐**(4)**	Fungalspot Disease.☐**(4)**		21-25 years ago…☐**(4)**
5. *Chilocoruscircumdatus* (Ladybird beetle)……☐**(5)**	Navalete Oranges…☐**(5)**	Black scales..☐**(5)**	Gummosis fungal disease ………..☐**(5)**		26-30 years ago…☐**(5)**
6. *Chilocorus baileyi* (Ladybird beetle……☐**(6)**	Newhall oranges….☐**(6)**	Broad mites...☐**(6)**	Melanos fungal disease..☐ **(6)**		More than 30 years.☐**(6)**
7. *Cryptolaemus montrouzieri* (Mealybugpredator)…☐**(7)**	Valencis oranges …………..☐**(7)**	Brown aphids.☐**(7)**	Root rot fungal disease..☐ **(7)**		
8. *Dalotia coriaria* (Rove beetle) ……………..☐**(8)**	Washington oranges.....☐**(8)**	Bud mites. ………..☐**(8)**	Others...☐ **(8)**		
9. *Encarsia formosa* (whitefly parasitoid)...☐**(9)**	Elendale mandarins...☐**(9)**	Red scales. ………..☐**(9)**			
10. *Eretmocerus warrae* (Whitefly parasitoid)…... …………………….☐**(10)**	Imperial Mandarins.☐**(10)**	Chinease rose beetle…. ………☐**(10)**			
11. *Hypoaspis aculeifer* (Fungus gnat predator) …………………….☐**(11)**	Murcott Mandarins …………..☐**(11)**	Fungus gnat**.** ………..☐**(11)**			
12. *Leptomastix dactylopii* (Citrusmealybugparasitoid) …………………….☐**(12)**	Ortanique Mandarin ……….....☐**(12)**	Katydids ………☐**(12)**			
13. *Mallada signata* (Green lacewing)…………☐**(13)**	Grapefruits ……….....☐**(13)**	Kelly's thrips…☐**(13)**			
14. *Neoseiulus cucumeris* (Cucumeris - predatory mite)………………☐**(14)**	Lemons ……….....☐**(14)**	Leaf miners ….. …..☐**(14)**			
15. *Neoseiulus wearnei* (predatory mite)…...☐**(15)**	Lime.... ……….....☐**(15)**	Locusts... ………☐**(15)**			
16. *Orius armatus* (Thrips predator)…………..☐**(16)**	Others…..☐**(16)**	Light brown Apple moth …… …..☐**(16)**			
17. *Phytoseiulus persimilis* (Persimilis-predatorymite)……☐**(17)**		Mealybugs. ………...☐**(17)**			
18. *Spalangia endius* (Flyparasitoid)……☐**(18)**		Mediterranean fruit flies☐**(18)**			
19. *Stratiolaelaps scimitus* (Predatory		Oriental fruitflies			

mite)……………...☐**(19)**		………☐**(19)**			
20. *Typhlodromus occidentalis* (Predatory mite)….☐**(20)**		Red spider Mites…☐**(20)**			
21. *Beddingia siricidicola* (Nematode)...........☐**(21)**		Rovebeetle ……….☐**(21)**			
22. *Heterorhabditis zealandica* (Nematode) …………………...☐**(22)**		Whiteflies…… ………☐**(22)**			
23. *Heterorhabditis bacteriophora* (Nematode)...........☐**(23)**		Others.. ……...☐**(23)**			
24. *Rhabditidae necromena* (Nematode) ……...☐**(24)**					
25. *Steinernema carpocapsae* (Nematode)………☐**(25)**					
26. *Steinernema feltiae* (Nematode)… …....☐**(26)**					
27 Others................☐**(27)**					

Others (please specify)

22. Answer this question only if you monitor biological control agents in your citrus orchards. If not please go to the next section. **(Code: C22)**

How often have you found the following biological control agents in your citrus orchards?

	Never **(1)**	Rarely **(2)**	Sometimes **(3)**	Very often **(4)**	Always **(5)**	
I have found parasitic wasps	☐	☐	☐	☐	☐	**(Code: C22 1)**
I have found predatory ladybird	☐	☐	☐	☐	☐	**(Code: C22 2)**
I have found predatory mite	☐	☐	☐	☐	☐	**(Code: C22 3)**
I have found Lacewings	☐	☐	☐	☐	☐	**(Code: C22 4)**
I have found Hoverflies	☐	☐	☐	☐	☐	**(Code: C22 5)**

Others (please specify) **(Code: C22 6)**

Section IV: Growers' perception (Please tick or write your response in appropriate boxes). **(Code: D)**

23. Please respond to the following statements about the requirements for practicing IPM compared with conventional practices. **(Code: D23)**

	Strongly Disagree **(1)**	Disagree **(2)**	Undecided **(3)**	Agree **(4)**	Strongly Agree **(5)**	
Using IPM requires more management time than conventional pest control	☐	☐	☐	☐	☐	**(Code: D23 1)**
IPM costs more than conventional pest control	☐	☐	☐	☐	☐	**(Code: D23 2)**
IPM requires more knowledge than conventional pest control	☐	☐	☐	☐	☐	**(Code: D23 3)**
IPM requires more labour than conventional pest control	☐	☐	☐	☐	☐	**(Code: D23 4)**

24. Answer this question if you use chemical pesticides in your citrus orchards. If not please go to the next question. **(Code: D24)**

To what extent do you agree with these statements about why you spray chemicals in your citrus orchards?

	Strongly Disagree (1)	Disagree (2)	Undecided (3)	Agree (4)	Strongly Agree (5)	
I use chemicals to control direct damage	☐	☐	☐	☐	☐	**(Code: D24 1)**
I use chemicals to control cosmetic damage	☐	☐	☐	☐	☐	**(Code: D24 2)**
I use chemicals to control both direct and cosmetic damage	☐	☐	☐	☐	☐	**(Code: D24 3)**

25. What is your response to these statements about the effect of insecticides on beneficial insects in your citrus orchards? **(Code: D25)**

	Strongly Disagree (1)	Disagree (2)	Undecided (3)	Agree (4)	Strongly Agree (5)	
Insecticides kill all beneficial insects	☐	☐	☐	☐	☐	**(Code: D25 1)**
Insecticides kill most of the beneficial Insects	☐	☐	☐	☐	☐	**(Code: D25 2)**
Insecticides kill some beneficial insects	☐	☐	☐	☐	☐	**(Code: D25 3)**
Insecticides don’t kill any beneficial insects	☐	☐	☐	☐	☐	**(Code: D25 4)**
Insecticides change beneficial insects’ effectiveness	☐	☐	☐	☐	☐	**(Code: D25 5)**

26. Please respond to the following statements about your insecticides application strategy for insect pest management in your citrus orchards. **(Code: D26)**

	Strongly Disagree (1)	Disagree (2)	Undecided (3)	Agree (4)	Strongly Agree (5)	
I do not use insecticides for pest management	☐	☐	☐	☐	☐	**(Code: D26 1)**
I make site–specific insecticide applications when needed	☐	☐	☐	☐	☐	**(Code: D26 2)**
I apply insecticides only when insect pests are present and risk is highest	☐	☐	☐	☐	☐	**(Code: D26 3)**
I apply insecticides only when economic threshold is met	☐	☐	☐	☐	☐	**(Code: D26 4)**
I rotate insecticide modes of action to reduce the risk of insecticides resistant pests	☐	☐	☐	☐	☐	**(Code: D26 5)**
I make variable-rate insecticide Applications	☐	☐	☐	☐	☐	**(Code: D26 6)**
I apply insecticides on a regular or calendar schedule	☐	☐	☐	☐	☐	**(Code: D26 7)**

27. Answer this question if you do not use biological control agents otherwise go the next question. Please respond to these following statements about why you do not use biological control agents in your citrus orchards? **(Code: D27)**

	Strongly Disagree **(1)**	Disagree **(2)**	Undecided **(3)**	Agree **(4)**	Strongly Agree **(5)**	
I have not considered using them	☐	☐	☐	☐	☐	**(Code: D27 1)**
I am not confident they will work	☐	☐	☐	☐	☐	**(Code: D27 2)**
I have tried them before but it was not effective	☐	☐	☐	☐	☐	**(Code: D27 3)**
They are too expensive	☐	☐	☐	☐	☐	**(Code: D27 4)**
They are not profitable	☐	☐	☐	☐	☐	**(Code: D27 5)**
They are too complicated	☐	☐	☐	☐	☐	**(Code: D27 6)**
They are too risky	☐	☐	☐	☐	☐	**(Code: D27 7)**
They are too labour intensive	☐	☐	☐	☐	☐	**(Code: D27 8)**
Too much training is needed	☐	☐	☐	☐	☐	**(Code: D27 9)**
I would need to hire a Consultant	☐	☐	☐	☐	☐	**(Code: D27 10)**
I think chemicals are more Effective	☐	☐	☐	☐	☐	**(Code: D27 11)**
I think chemicals are cheaper	☐	☐	☐	☐	☐	**(Code: D27 12)**
It is wasteful to use both chemicals and biological control together	☐	☐	☐	☐	☐	**(Code: D27 13)**
I never get desired results from biological control agent	☐	☐	☐	☐	☐	**(Code: D27 14)**

28. To what extent do you agree with the following statements about what influenced your decision to start using biological control agents in your citrus orchards? **(Code: D28)**

	Strongly Disagree **(1)**	Disagree **(2)**	Undecided **(3)**	Agree **(4)**	Strongly Agree **(5)**	
I started to use biological control agents because:						
I was convinced from my Education that it was worth doing	☐	☐	☐	☐	☐	**(Code: D28 1)**
I don't believe that we have a future with chemicals	☐	☐	☐	☐	☐	**(Code: D28 2)**
I have seen, that they work when I travelled overseas	☐	☐	☐	☐	☐	**(Code: D28 3)**
I am concerned about my health risks	☐	☐	☐	☐	☐	**(Code: D28 4)**
I am concerned about the Environment	☐	☐	☐	☐	☐	**(Code: D28 5)**
I think chemicals are not cost-effective	☐	☐	☐	☐	☐	**(Code: D28 6)**

Other (please specify) **(Code: D28 7)**

29. Answer this question if you use biological control agents. Please respond to the following statements that describe the reasons why you use biological control agents in your citrus orchards? **(Code: D29)**

I use biological control agents because:	Strongly Disagree **(1)**	Disagree **(2)**	Undecided **(3)**	Agree **(4)**	Strongly Agree **(5)**	
Pest insects have developed insecticide resistance	☐	☐	☐	☐	☐	(**Code: D29 1)**
An insecticide was withdrawn	☐	☐	☐	☐	☐	**(Code: D29 2)**
It is profitable	☐	☐	☐	☐	☐	**(Code: D29 3)**
It is relatively cheap	☐	☐	☐	☐	☐	**(Code: D29 4)**
It is effective	☐	☐	☐	☐	☐	**(Code: D29 5)**
It helps IPM	☐	☐	☐	☐	☐	**(Code: D29 6)**
It is safer for the health of me and my family	☐	☐	☐	☐	☐	**(Code: D29 7)**
It is safer for the environment	☐	☐	☐	☐	☐	**(Code: D29 8)**

Other (please specify) **(Code: D29 9)**

[ ]

30. Please respond to the following statements that describe your (non-users) attitude to the use of biological control agents in your orchards in future? **(Code: D30)**

I will use biological control agents in future if:

	Strongly Disagree **(1)**	Disagree **(2)**	Undecided **(3)**	Agree **(4)**	Strongly Agree **(5)**	
consumers accept blemishes in fruit and vegetables	☐	☐	☐	☐	☐	**(Code: D30 1)**
a suite of biological control agents is available for all pests	☐	☐	☐	☐	☐	**(Code: D30 2)**
biological control agents become cheaper and more effective	☐	☐	☐	☐	☐	**(Code: D30 3)**
retailers put pressure on supplier to use biological control agents	☐	☐	☐	☐	☐	**(Code: D30 4)**
government creates new laws that require the use of biological control	☐	☐	☐	☐	☐	**(Code: D30 5)**

Others (please specify) **(Code: D30 6)**

[ ]

Section V: Technology characteristics **(Code: E)**

Please only answer this section if you use biological control agents. If you don't, then go to the next section (Please tick or write your response in appropriate boxes).

31. To what extent do you agree with the following statements about the use of biological control agents such as *Aphytis* on your citrus orchards? **(Code: E31)**

	Strongly Disagree **(1)**	Disagree **(2)**	Undecided **(3)**	Agree **(4)**	Strongly Agree **(5)**	
No biological control agents are commercially available for other pests other than red scales	☐	☐	☐	☐	☐	**(Code: E31 1)**

Aphytis only attack certain stages of red scales	☐	☐	☐	☐	☐ **(Code: E31 2)**
Aphytis control red scales only in certain citrus varieties	☐	☐	☐	☐	☐ **(Code: E31 3)**
I need training before using biological control agents	☐	☐	☐	☐	☐ **(Code: E31 4)**
Using biological control agent is lobour intensive	☐	☐	☐	☐	☐ **(Code: E31 5)**
I need a consultant to use biological control agent	☐	☐	☐	☐	☐ **(Code: E31 6)**

Others (please specify) **(Code: E31 7)**

32. After release of biological control agents how soon would you apply pesticides? **(Code: E32)**

	No(1)	Yes (2)
Less than one week	☐	☐ **(Code: E32 1)**
One - three weeks	☐	☐ **(Code: E32 2)**
More than three weeks	☐	☐ **(Code: E32 3)**
Four- five weeks	☐	☐ **(Code: E32 4)**
More than five weeks	☐	☐ **(Code: E33 5)**

Section VI: Institutional factors (Please tick or write your response in appropriate boxes) **(Code: F)**

33. What are your sources of information on the topic of pest management? **(Code: F33)**

	No (1)	Yes (2)
Workshops	☐	☐ **(Code: F33..1)**
Field days	☐	☐ **(Code: F 33 2)**
Pamphlets	☐	☐ **(Code: F 33 3)**
Other farmers	☐	☐ **(Code: F 33 4)**
Insectary companies	☐	☐ **(Code: F 33 5)**
Haven't heard	☐	☐ **(Code: F 33 6)**

Others sources (please specify) **(Code: F 33 7)**

34. Do you get any help from government or any other organizations about pest management on your citrus orchards? **(Code: F43)**

	Strongly Disagree **(1)**	Disagree **(2)**	Undecided **(3)**	Agree **(4)**	Strongly Agree **(5)**
I receive consultation from Government	☐	☐	☐	☐	☐ **(Code: F 34 1)**
I receive consultation from agricultural chemical companies	☐	☐	☐	☐	☐ **(Code: F 34 2)**
I received consultation from incestary companies	☐	☐	☐	☐	☐ **(Code: F 34 3)**
I receive consultation from other Organizations	☐	☐	☐	☐	☐ **(Code: F 34 5)**
Government provides me monitoring services only	☐	☐	☐	☐	☐ **(Code: F 34 6)**
Agricultural chemical companies provides me monitoring services only	☐	☐	☐	☐	☐ **(Code: F 34 7)**
Insectary companies provide me monitoring services only	☐	☐	☐	☐	☐ **(Code: F 34 8)**
Other organizations provide me monitoring service only	☐	☐	☐	☐	☐ **(Code: F 34 9)**

Government, insectary companies and other organizations provide me information	☐	☐	☐	☐	☐ **(Code: F 34 10)**
Government subsidized my citrus orchards	☐	☐	☐	☐	☐ **(Code: F 34 11)**
I don't get any help from government or other organizations except information	☐	☐	☐	☐	☐ **(Code: F 34 12)**

Others (please specify) **(Code: F 34 13)**

If you are interested in hearing about the results from this survey then please provide us your contact details i.e. mailing address, email address.

If you want to participate in the survey but would prefer to complete a printed survey or complete it by telephone, please contact Mahmuda Begum on 02 8627 1064 or by email: mahmuda.begum@sydney.edu.au

Please feel free to tell other citrus growers to contact me for printed copy of this questionnaire. Thank you for completing this form.

Your contact details

Postal Address: Tel: Email:

Appendix 11: Summary statistics of citrus growers survey data that is referenced in the text (Chapter 6, result section). This Appendix includes nine questions and analyses for Questions C12, C14, C15, C18, C19, D24, D26, E32 and F34.

Question C12: This question was for both USERS and NON-USERS.

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Oranges * Biological control agents (BCA)	69	95.8%	3	4.2%	72	100.0%
Mandarins * Biological control agents (BCA)	46	63.9%	26	36.1%	72	100.0%
Lemons * Biological control agents (BCA)	27	37.5%	45	62.5%	72	100.0%
Limes * Biological control agents (BCA)	20	27.8%	52	72.2%	72	100.0%
Grapefruits * Biological control agents (BCA)	27	37.5%	45	62.5%	72	100.0%
Others * Biological control agents (BCA)	8	11.1%	64	88.9%	72	100.0%

Oranges * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Oranges	N/A	Count	3	1	4
		% within Oranges	75.0%	25.0%	100.0%
		% within Biological control agents (BCA)	9.1%	2.8%	5.8%
		% of Total	4.3%	1.4%	5.8%
	1%-25%	Count	2	2	4
		% within Oranges	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	6.1%	5.6%	5.8%
		% of Total	2.9%	2.9%	5.8%
	26%-50%	Count	4	2	6
		% within Oranges	66.7%	33.3%	100.0%
		% within Biological control agents (BCA)	12.1%	5.6%	8.7%
		% of Total	5.8%	2.9%	8.7%
	51%-75%	Count	10	15	25
		% within Oranges	40.0%	60.0%	100.0%
		% within Biological control agents (BCA)	30.3%	41.7%	36.2%
		% of Total	14.5%	21.7%	36.2%
	76%-100%	Count	14	16	30
		% within Oranges	46.7%	53.3%	100.0%
		% within Biological control agents (BCA)	42.4%	44.4%	43.5%
		% of Total	20.3%	23.2%	43.5%
Total		Count	33	36	69
		% within Oranges	47.8%	52.2%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	47.8%	52.2%	100.0%

Mandarins * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Mandarins	N/A	Count	1	1	2
		% within Mandarins	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	4.3%	4.3%	4.3%
		% of Total	2.2%	2.2%	4.3%
	1%-25%	Count	8	16	24
		% within Mandarins	33.3%	66.7%	100.0%
		% within Biological control agents (BCA)	34.8%	69.6%	52.2%
		% of Total	17.4%	34.8%	52.2%
	26%-50%	Count	7	1	8
		% within Mandarins	87.5%	12.5%	100.0%
		% within Biological control agents (BCA)	30.4%	4.3%	17.4%
		% of Total	15.2%	2.2%	17.4%

	51%-75%	Count	5	5	10
		% within Mandarins	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	21.7%	21.7%	21.7%
		% of Total	10.9%	10.9%	21.7%
	76%-100%	Count	2	0	2
		% within Mandarins	100.0%	0.0%	100.0%
		% within Biological control agents (BCA)	8.7%	0.0%	4.3%
		% of Total	4.3%	0.0%	4.3%
Total		Count	23	23	46
		% within Mandarins	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	50.0%	50.0%	100.0%

Lemons * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Lemons	N/A	Count	1	2	3
		% within Lemons	33.3%	66.7%	100.0%
		% within Biological control agents (BCA)	7.7%	14.3%	11.1%
		% of Total	3.7%	7.4%	11.1%
	1%-25%	Count	9	11	20
		% within Lemons	45.0%	55.0%	100.0%
		% within Biological control agents (BCA)	69.2%	78.6%	74.1%
		% of Total	33.3%	40.7%	74.1%
	26%-50%	Count	3	1	4
		% within Lemons	75.0%	25.0%	100.0%
		% within Biological control agents (BCA)	23.1%	7.1%	14.8%
		% of Total	11.1%	3.7%	14.8%
Total		Count	13	14	27
		% within Lemons	48.1%	51.9%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	48.1%	51.9%	100.0%

Limes * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Limes	N/A	Count	4	4	8
		% within Limes	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	30.8%	57.1%	40.0%
		% of Total	20.0%	20.0%	40.0%
	1%-25%	Count	9	3	12
		% within Limes	75.0%	25.0%	100.0%
		% within Biological control agents (BCA)	69.2%	42.9%	60.0%
		% of Total	45.0%	15.0%	60.0%
Total		Count	13	7	20
		% within Limes	65.0%	35.0%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	65.0%	35.0%	100.0%

Grapefruits * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Grapefruits	N/A	Count	4	4	8
		% within Grapefruits	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	28.6%	30.8%	29.6%
		% of Total	14.8%	14.8%	29.6%
	1%-25%	Count	9	9	18
		% within Grapefruits	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	64.3%	69.2%	66.7%
		% of Total	33.3%	33.3%	66.7%

	26%-50%	Count	1	0	1
		% within Grapefruits	100.0%	0.0%	100.0%
		% within Biological control agents (BCA)	7.1%	0.0%	3.7%
		% of Total	3.7%	0.0%	3.7%
Total		Count	14	13	27
		% within Grapefruits	51.9%	48.1%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	51.9%	48.1%	100.0%

Others * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Others	N/A	Count	1	3	4
		% within Others	25.0%	75.0%	100.0%
		% within Biological control agents (BCA)	25.0%	75.0%	50.0%
		% of Total	12.5%	37.5%	50.0%
	1%-25%	Count	3	0	3
		% within Others	100.0%	0.0%	100.0%
		% within Biological control agents (BCA)	75.0%	0.0%	37.5%
		% of Total	37.5%	0.0%	37.5%
	26%-50%	Count	0	1	1
		% within Others	0.0%	100.0%	100.0%
		% within Biological control agents (BCA)	0.0%	25.0%	12.5%
		% of Total	0.0%	12.5%	12.5%
Total		Count	4	4	8
		% within Others	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	50.0%	50.0%	100.0%

Question C14: This question was for both USERS and NON-USERS.

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Intercrop citrus with other crops * Biological control agents (BCA)	71	98.6%	1	1.4%	72	100.0%

Intercrop citrus with other crops * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Intercrop citrus with other crops	No	Count	31	34	65
		% within Intercrop ctrus with other crops	47.7%	52.3%	100.0%
		% within Biological control agents (BCA)	91.2%	91.9%	91.5%
		% of Total	43.7%	47.9%	91.5%
	Yes	Count	3	3	6
		% within Intercrop ctrus with other crops	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	8.8%	8.1%	8.5%
		% of Total	4.2%	4.2%	8.5%
Total		Count	34	37	71
		% within Intercrop ctrus with other crops	47.9%	52.1%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	47.9%	52.1%	100.0%

Question C15: This question was for both USERS and NON-USERS.

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Orchard floor covered with Clovers * Biological control agents (BCA)	48	66.7%	24	33.3%	72	100.0%
Orchard floor covered with Broad Beans * Biological control agents (BCA)	36	50.0%	36	50.0%	72	100.0%
Orchard floor covered with Grasses * Biological control agents (BCA)	57	79.2%	15	20.8%	72	100.0%
Orchard floor is kept bare * Biological control agents(BCA)	40	55.6%	32	44.4%	72	100.0%
Others * Biological control agents (BCA)	24	33.3%	48	66.7%	72	100.0%

Orchard floor covered with Clovers * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Orchard floor covered with Clovers	No	Count	21	12	33
		% within Orchard floor covered with Clovers	63.6%	36.4%	100.0%
		% within Biological control agents (BCA)	84.0%	52.2%	68.8%
		% of Total	43.8%	25.0%	68.8%
	Yes	Count	4	11	15
		% within Orchard floor covered with Clovers	26.7%	73.3%	100.0%
		% within Biological control agents (BCA)	16.0%	47.8%	31.3%
		% of Total	8.3%	22.9%	31.3%
Total		Count	25	23	48
		% within Orchard floor covered with Clovers	52.1%	47.9%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	52.1%	47.9%	100.0%

Orchard floor covered with Broad Beans * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Orchard floor covered with Broad Beans	No	Count	21	14	35
		% within Orchard floor covered with Broad Beans	60.0%	40.0%	100.0%
		% within Biological control agents (BCA)	95.5%	100.0%	97.2%
		% of Total	58.3%	38.9%	97.2%
	Yes	Count	1	0	1
		% within Orchard floor covered with Broad Beans	100.0%	0.0%	100.0%
		% within Biological control agents (BCA)	4.5%	0.0%	2.8%
		% of Total	2.8%	0.0%	2.8%
Total		Count	22	14	36
		% within Orchard floor covered with Broad Beans	61.1%	38.9%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	61.1%	38.9%	100.0%

Orchard floor covered with Grasses * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Orchard floor covered with Grasses	No	Count	6	6	12
		% within Orchard floor covered with Grasses	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	20.7%	21.4%	21.1%
		% of Total	10.5%	10.5%	21.1%
	Yes	Count	23	22	45
		% within Orchard floor covered with Grasses	51.1%	48.9%	100.0%
		% within Biological control agents (BCA)	79.3%	78.6%	78.9%
		% of Total	40.4%	38.6%	78.9%
Total		Count	29	28	57
		% within Orchard floor covered with Grasses	50.9%	49.1%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	50.9%	49.1%	100.0%

Orchard floor is kept bare * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Orchard floor is kept bare	No	Count	14	9	23
		% within Orchard floor is kept bare	60.9%	39.1%	100.0%
		% within Biological control agents (BCA)	66.7%	47.4%	57.5%
		% of Total	35.0%	22.5%	57.5%
	Yes	Count	7	10	17
		% within Orchard floor is kept bare	41.2%	58.8%	100.0%
		% within Biological control agents (BCA)	33.3%	52.6%	42.5%
		% of Total	17.5%	25.0%	42.5%
Total		Count	21	19	40
		% within Orchard floor is kept bare	52.5%	47.5%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	52.5%	47.5%	100.0%

Others * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Others	No	Count	4	8	12
		% within Others	33.3%	66.7%	100.0%
		% within Biological control agents (BCA)	40.0%	57.1%	50.0%
		% of Total	16.7%	33.3%	50.0%
	Yes	Count	6	6	12
		% within Others	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	60.0%	42.9%	50.0%
		% of Total	25.0%	25.0%	50.0%
Total		Count	10	14	24
		% within Others	41.7%	58.3%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	41.7%	58.3%	100.0%

Question C18: This question was for both USERS and NON-USERS.

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Follow the economic threshold * Biological control agents (BCA)	70	97.2%	2	2.8%	72	100.0%

Follow the economic threshold * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Follow the economic threshold	No	Count	3	4	7
		% within Follow the economic threshold	42.9%	57.1%	100.0%
		% within Biological control agents (BCA)	8.8%	11.1%	10.0%
		% of Total	4.3%	5.7%	10.0%
	Yes	Count	27	25	52
		% within Follow the economic threshold	51.9%	48.1%	100.0%
		% within Biological control agents (BCA)	79.4%	69.4%	74.3%
		% of Total	38.6%	35.7%	74.3%
	Don't Know	Count	4	7	11
		% within Follow the economic threshold	36.4%	63.6%	100.0%
		% within Biological control agents (BCA)	11.8%	19.4%	15.7%
		% of Total	5.7%	10.0%	15.7%
Total		Count	34	36	70
		% within Follow the economic threshold	48.6%	51.4%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	48.6%	51.4%	100.0%

Question C19: This question was for both USER and NON-USERS.

Case Processing Summary						
	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Measure economic threshold * Biological control agents (BCA)	49	68.1%	23	31.9%	72	100.0%

Measure economic threshold * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Measure economic threshold	Monitoring	Count	13	16	29
		% within Measure economic threshold	44.8%	55.2%	100.0%
		% within Biological control agents (BCA)	54.2%	64.0%	59.2%
		% of Total	26.5%	32.7%	59.2%
	Fruit doctors or consultants	Count	4	3	7
		% within Measure economic threshold	57.1%	42.9%	100.0%
		% within Biological control agents (BCA)	16.7%	12.0%	14.3%
		% of Total	8.2%	6.1%	14.3%
	Others	Count	7	6	13
		% within Measure economic threshold	53.8%	46.2%	100.0%
		% within Biological control agents (BCA)	29.2%	24.0%	26.5%
		% of Total	14.3%	12.2%	26.5%
Total		Count	24	25	49
		% within Measure economic threshold	49.0%	51.0%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	49.0%	51.0%	100.0%

Question D24: This question was for both USERS and NON-USERS.

Case Processing Summary						
	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Use chemicals to control direct damage * Biological control agents (BCA)	52	72.2%	20	27.8%	72	100.0%
Use chemicals to control cosmetic damage * Biological control agents (BCA)	48	66.7%	24	33.3%	72	100.0%
Use chemicals to control both direct and cosmetic damage * Biological control agents (BCA)	50	69.4%	22	30.6%	72	100.0%

Use chemicals to control direct damage * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Use chemicals to control direct damage	Disagree	Count	1	0	1
		% within Use chemicals to control direct damage	100.0%	0.0%	100.0%
		% within Biological control agents (BCA)	4.0%	0.0%	1.9%
		% of Total	1.9%	0.0%	1.9%
	Undecided	Count	1	2	3
		% within Use chemicals to control direct damage	33.3%	66.7%	100.0%
		% within Biological control agents (BCA)	4.0%	7.4%	5.8%
		% of Total	1.9%	3.8%	5.8%
	Agree	Count	18	20	38
		% within Use chemicals to control direct damage	47.4%	52.6%	100.0%
		% within Biological control agents (BCA)	72.0%	74.1%	73.1%
		% of Total	34.6%	38.5%	73.1%
	Strongly Agree	Count	5	5	10
		% within Use chemicals to control direct damage	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	20.0%	18.5%	19.2%
		% of Total	9.6%	9.6%	19.2%

Total	Count	25	27	52
	% within Use chemicals to control direct damage	48.1%	51.9%	100.0%
	% within Biological control agents (BCA)	100.0%	100.0%	100.0%
	% of Total	48.1%	51.9%	100.0%

Use chemicals to control cosmetic damage * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Use chemicals to control cosmetic damage	Strongly Disagree	Count	4	0	4
		% within Use chemicals to control cosmetic damage	100.0%	0.0%	100.0%
		% within Biological control agents (BCA)	17.4%	0.0%	8.3%
		% of Total	8.3%	0.0%	8.3%
	Disagree	Count	2	1	3
		% within Use chemicals to control cosmetic damage	66.7%	33.3%	100.0%
		% within Biological control agents (BCA)	8.7%	4.0%	6.3%
		% of Total	4.2%	2.1%	6.3%
	Undecided	Count	1	3	4
		% within Use chemicals to control cosmetic damage	25.0%	75.0%	100.0%
		% within Biological control agents (BCA)	4.3%	12.0%	8.3%
		% of Total	2.1%	6.3%	8.3%
	Agree	Count	12	18	30
		% within Use chemicals to control cosmetic damage	40.0%	60.0%	100.0%
		% within Biological control agents (BCA)	52.2%	72.0%	62.5%
		% of Total	25.0%	37.5%	62.5%
	Strongly Agree	Count	4	3	7
		% within Use chemicals to control cosmetic damage	57.1%	42.9%	100.0%
		% within Biological control agents (BCA)	17.4%	12.0%	14.6%
		% of Total	8.3%	6.3%	14.6%
Total		Count	23	25	48
		% within Use chemicals to control cosmetic damage	47.9%	52.1%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	47.9%	52.1%	100.0%

Use chemicals to control both direct and cosmetic damage * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Use chemicals to control both direct and cosmetic damage	Strongly Disagree	Count	4	0	4
		% within Use chemicals to control both direct and cosmetic damage	100.0%	0.0%	100.0%
		% within Biological control agents (BCA)	16.7%	0.0%	8.0%
		% of Total	8.0%	0.0%	8.0%
	Disagree	Count	2	1	3
		% within Use chemicals to control both direct and cosmetic damage	66.7%	33.3%	100.0%
		% within Biological control agents (BCA)	8.3%	3.8%	6.0%
		% of Total	4.0%	2.0%	6.0%
	Undecided	Count	0	2	2
		% within Use chemicals to control both direct and cosmetic damage	0.0%	100.0%	100.0%
		% within Biological control agents (BCA)	0.0%	7.7%	4.0%
		% of Total	0.0%	4.0%	4.0%
	Agree	Count	13	21	34
		% within Use chemicals to control both direct and cosmetic damage	38.2%	61.8%	100.0%
		% within Biological control agents (BCA)	54.2%	80.8%	68.0%
		% of Total	26.0%	42.0%	68.0%

	Strongly Agree	Count	5	2	7
		% within Use chemicals to control both direct and cosmetic damage	71.4%	28.6%	100.0%
		% within Biological control agents (BCA)	20.8%	7.7%	14.0%
		% of Total	10.0%	4.0%	14.0%
Total		Count	24	26	50
		% within Use chemicals to control both direct and cosmetic damage	48.0%	52.0%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	48.0%	52.0%	100.0%

Question D26: This question was for both USERS and NON-USERS.

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Not use insecticides * Biological control agents (BCA)	58	80.6%	14	19.4%	72	100.0%
make site-specific insecticide application * Biological control agents (BCA)	62	86.1%	10	13.9%	72	100.0%
Apply insecticides when risk is highest * Biological control agents (BCA)	62	86.1%	10	13.9%	72	100.0%
Apply insecticides when economic threshold met * Biological control agents (BCA)	61	84.7%	11	15.3%	72	100.0%
Rotate insecticides modes of action * Biological control agents (BCA)	58	80.6%	14	19.4%	72	100.0%
Make variable-rate insecticide applications * Biological control agents (BCA)	58	80.6%	14	19.4%	72	100.0%
Apply insecticide regular or clender schedule * Biological control agents (BCA)	57	79.2%	15	20.8%	72	100.0%

Not use insecticides * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Not use insecticides	Strongly Disagree	Count	9	12	21
		% within Not use insecticides	42.9%	57.1%	100.0%
		% within Biological control agents (BCA)	30.0%	42.9%	36.2%
		% of Total	15.5%	20.7%	36.2%
	Disagree	Count	15	8	23
		% within Not use insecticides	65.2%	34.8%	100.0%
		% within Biological control agents (BCA)	50.0%	28.6%	39.7%
		% of Total	25.9%	13.8%	39.7%
	Undecided	Count	0	3	3
		% within Not use insecticides	0.0%	100.0%	100.0%
		% within Biological control agents (BCA)	0.0%	10.7%	5.2%
		% of Total	0.0%	5.2%	5.2%
	Agree	Count	3	5	8
		% within Not use insecticides	37.5%	62.5%	100.0%
		% within Biological control agents (BCA)	10.0%	17.9%	13.8%
		% of Total	5.2%	8.6%	13.8%
	Strongly Agree	Count	3	0	3
		% within Not use insecticides	100.0%	0.0%	100.0%
		% within Biological control agents (BCA)	10.0%	0.0%	5.2%
		% of Total	5.2%	0.0%	5.2%
Total		Count	30	28	58
		% within Not use insecticides	51.7%	48.3%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	51.7%	48.3%	100.0%

make site-specific insecticide application * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
make site-specific insecticide application	Strongly Disagree	Count	1	1	2
		% within make site-specific insecticide application	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	3.3%	3.1%	3.2%
		% of Total	1.6%	1.6%	3.2%
	Disagree	Count	0	2	2
		% within make site-specific insecticide application	0.0%	100.0%	100.0%
		% within Biological control agents (BCA)	0.0%	6.3%	3.2%
		% of Total	0.0%	3.2%	3.2%
	Undecided	Count	0	1	1
		% within make site-specific insecticide application	0.0%	100.0%	100.0%
		% within Biological control agents (BCA)	0.0%	3.1%	1.6%
		% of Total	0.0%	1.6%	1.6%
	Agree	Count	14	17	31
		% within make site-specific insecticide application	45.2%	54.8%	100.0%
		% within Biological control agents (BCA)	46.7%	53.1%	50.0%
		% of Total	22.6%	27.4%	50.0%
	Strongly Agree	Count	15	11	26
		% within make site-specific insecticide application	57.7%	42.3%	100.0%
		% within Biological control agents (BCA)	50.0%	34.4%	41.9%
		% of Total	24.2%	17.7%	41.9%
Total		Count	30	32	62
		% within make site-specific insecticide application	48.4%	51.6%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	48.4%	51.6%	100.0%

Apply insecticides when risk is highest * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Apply insecticides when risk is highest	Strongly Disagree	Count	1	0	1
		% within Apply insecticides when risk is highest	100.0%	0.0%	100.0%
		% within Biological control agents (BCA)	3.3%	0.0%	1.6%
		% of Total	1.6%	0.0%	1.6%
	Disagree	Count	1	1	2
		% within Apply insecticides when risk is highest	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	3.3%	3.1%	3.2%
		% of Total	1.6%	1.6%	3.2%
	Undecided	Count	0	2	2
		% within Apply insecticides when risk is highest	0.0%	100.0%	100.0%
		% within Biological control agents (BCA)	0.0%	6.3%	3.2%
		% of Total	0.0%	3.2%	3.2%
	Agree	Count	12	17	29
		% within Apply insecticides when risk is highest	41.4%	58.6%	100.0%
		% within Biological control agents (BCA)	40.0%	53.1%	46.8%
		% of Total	19.4%	27.4%	46.8%
	Strongly Agree	Count	16	12	28
		% within Apply insecticides when risk is highest	57.1%	42.9%	100.0%
		% within Biological control agents (BCA)	53.3%	37.5%	45.2%
		% of Total	25.8%	19.4%	45.2%

Total	Count	30	32	62
	% within Apply insecticides when risk is highest	48.4%	51.6%	100.0%
	% within Biological control agents (BCA)	100.0%	100.0%	100.0%
	% of Total	48.4%	51.6%	100.0%

Apply insecticides when economic threshold met * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Apply insecticides when economic threshold met	Strongly Disagree	Count	1	1	2
		% within Apply insecticides when economic threshold met	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	3.3%	3.2%	3.3%
		% of Total	1.6%	1.6%	3.3%
	Disagree	Count	4	6	10
		% within Apply insecticides when economic threshold met	40.0%	60.0%	100.0%
		% within Biological control agents (BCA)	13.3%	19.4%	16.4%
		% of Total	6.6%	9.8%	16.4%
	Undecided	Count	3	7	10
		% within Apply insecticides when economic threshold met	30.0%	70.0%	100.0%
		% within Biological control agents (BCA)	10.0%	22.6%	16.4%
		% of Total	4.9%	11.5%	16.4%
	Agree	Count	12	10	22
		% within Apply insecticides when economic threshold met	54.5%	45.5%	100.0%
		% within Biological control agents (BCA)	40.0%	32.3%	36.1%
		% of Total	19.7%	16.4%	36.1%
	Strongly Agree	Count	10	7	17
		% within Apply insecticides when economic threshold met	58.8%	41.2%	100.0%
		% within Biological control agents (BCA)	33.3%	22.6%	27.9%
		% of Total	16.4%	11.5%	27.9%
Total		Count	30	31	61
		% within Apply insecticides when economic threshold met	49.2%	50.8%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	49.2%	50.8%	100.0%

Rotate insecticides modes of action * Biological control agents (BCA) Crosstabulation

			Biological control agents(BCA)		Total
			BCA user	BCA non-user	
Rotate insecticides modes of action	Strongly Disagree	Count	1	0	1
		% within Rotate insecticides modes of action	100.0%	0.0%	100.0%
		% within Biological control agents (BCA)	3.4%	0.0%	1.7%
		% of Total	1.7%	0.0%	1.7%
	Disagree	Count	3	8	11
		% within Rotate insecticides modes of action	27.3%	72.7%	100.0%
		% within Biological control agents (BCA)	10.3%	27.6%	19.0%
		% of Total	5.2%	13.8%	19.0%
	Undecided	Count	3	5	8
		% within Rotate insecticides modes of action	37.5%	62.5%	100.0%
		% within Biological control agents (BCA)	10.3%	17.2%	13.8%
		% of Total	5.2%	8.6%	13.8%
	Agree	Count	11	11	22
		% within Rotate insecticides modes of action	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	37.9%	37.9%	37.9%
		% of Total	19.0%	19.0%	37.9%
	Strongly Agree	Count	11	5	16
		% within Rotate insecticides modes of action	68.8%	31.3%	100.0%
		% within Biological control agents (BCA)	37.9%	17.2%	27.6%
		% of Total	19.0%	8.6%	27.6%

Total	Count	29	29	58
	% within Rotate insecticides modes of action	50.0%	50.0%	100.0%
	% within Biological control agents (BCA)	100.0%	100.0%	100.0%
	% of Total	50.0%	50.0%	100.0%

Make variable-rate insecticide applications * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Make variable-rate insecticide applications	Strongly Disagree	Count	2	4	6
		% within Make variable-rate insecticide applications	33.3%	66.7%	100.0%
		% within Biological control agents (BCA)	7.1%	13.3%	10.3%
		% of Total	3.4%	6.9%	10.3%
	Disagree	Count	6	8	14
		% within Make variable-rate insecticide applications	42.9%	57.1%	100.0%
		% within Biological control agents (BCA)	21.4%	26.7%	24.1%
		% of Total	10.3%	13.8%	24.1%
	Undecided	Count	3	5	8
		% within Make variable-rate insecticide applications	37.5%	62.5%	100.0%
		% within Biological control agents (BCA)	10.7%	16.7%	13.8%
		% of Total	5.2%	8.6%	13.8%
	Agree	Count	9	11	20
		% within Make variable-rate insecticide applications	45.0%	55.0%	100.0%
		% within Biological control agents (BCA)	32.1%	36.7%	34.5%
		% of Total	15.5%	19.0%	34.5%
	Strongly Agree	Count	8	2	10
		% within Make variable-rate insecticide applications	80.0%	20.0%	100.0%
		% within Biological control agents (BCA)	28.6%	6.7%	17.2%
		% of Total	13.8%	3.4%	17.2%
		Count	28	30	58
		% within Make variable-rate insecticide applications	48.3%	51.7%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	48.3%	51.7%	100.0%

Apply insecticide regular or clender schedule * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Apply insecticide regular or clender schedule	Strongly Disagree	Count	16	14	30
		% within Apply insecticide regular or clender schedule	53.3%	46.7%	100.0%
		% within Biological control agents (BCA)	59.3%	46.7%	52.6%
		% of Total	28.1%	24.6%	52.6%
	Disagree	Count	9	10	19
		% within Apply insecticide regular or clender schedule	47.4%	52.6%	100.0%
		% within Biological control agents (BCA)	33.3%	33.3%	33.3%
		% of Total	15.8%	17.5%	33.3%
	Undecided	Count	0	1	1
		% within Apply insecticide regular or clender schedule	0.0%	100.0%	100.0%
		% within Biological control agents (BCA)	0.0%	3.3%	1.8%
		% of Total	0.0%	1.8%	1.8%

	Agree	Count	2	4	6
		% within Apply insecticide regular or clender schedule	33.3%	66.7%	100.0%
		% within Biological control agents (BCA)	7.4%	13.3%	10.5%
		% of Total	3.5%	7.0%	10.5%
	Strongly Agree	Count	0	1	1
		% within Apply insecticide regular or clender schedule	0.0%	100.0%	100.0%
		% within Biological control agents (BCA)	0.0%	3.3%	1.8%
		% of Total	0.0%	1.8%	1.8%
Total		Count	27	30	57
		% within Apply insecticide regular or clender schedule	47.4%	52.6%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	47.4%	52.6%	100.0%

Question E32: This question was for USERS only.

Biological control agents (BCA) = BCA user

Statistics[a]

	Less than one week	One-three weeks	More than three weeks	Four-five weeks	More than five weeks
N Valid	15	18	18	15	21
Missing	16	13	13	16	10

a. Biological control agents (BCA) = BCA user

Frequency Table

Less than one week[a]

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	15	48.4	100.0	100.0
Missing	99	16	51.6		
Total		31	100.0		

a. Biological control agents (BCA) = BCA user

One-three weeks[a]

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	14	45.2	77.8	77.8
	Yes	4	12.9	22.2	100.0
	Total	18	58.1	100.0	
Missing	99	13	41.9		
Total		31	100.0		

a. Biological control agents (BCA) = BCA user

More than three weeks[a]

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	12	38.7	66.7	66.7
	Yes	6	19.4	33.3	100.0
	Total	18	58.1	100.0	
Missing	99	13	41.9		
Total		31	100.0		

a. Biological control agents (BCA) = BCA user

Four-five weeks[a]

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	13	41.9	86.7	86.7
	Yes	2	6.5	13.3	100.0
	Total	15	48.4	100.0	
Missing	99	16	51.6		
Total		31	100.0		

a. Biological control agents (BCA) = BCA user

More than five weeks[a]

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	8	25.8	38.1	38.1
	Yes	13	41.9	61.9	100.0
	Total	21	67.7	100.0	
Missing	99	10	32.3		
Total		31	100.0		

a. Biological control agents (BCA) = BCA user

Question F34: This question was for both USERS and NON-USERS.

Case Processing Summary						
	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Received consultation from government * Biological control agents (BCA)	60	83.3%	12	16.7%	72	100.0%
Received consultation from chemical companies * Biological control agents (BCA)	59	81.9%	13	18.1%	72	100.0%
Received consultation from insectary companies * Biological control agents (BCA)	59	81.9%	13	18.1%	72	100.0%
Received consultation from other companies * Biological control agents (BCA)	59	81.9%	13	18.1%	72	100.0%
Government provides monitoring services * Biological control agents (BCA)	58	80.6%	14	19.4%	72	100.0%
Chemical companies provides monitoring services * Biological control agents (BCA)	57	79.2%	15	20.8%	72	100.0%
Insectary companies provides monitoring services * Biological control agents (BCA)	57	79.2%	15	20.8%	72	100.0%
Other organosations provide monitoring services * Biological control agents (BCA)	57	79.2%	15	20.8%	72	100.0%
Government, insectary companies and other organisation provides information * Biological control agents (BCA)	57	79.2%	15	20.8%	72	100.0%
Government subsidized citrus farm * Biological control agents (BCA)	56	77.8%	16	22.2%	72	100.0%
Don't get any help except information * Biological control agents (BCA)	60	83.3%	12	16.7%	72	100.0%

Received consultation from government * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Received consultation from government	Strongly Disagree	Count	11	14	25
		% within Received consultation from government	44.0%	56.0%	100.0%
		% within Biological control agents (BCA)	35.5%	48.3%	41.7%
		% of Total	18.3%	23.3%	41.7%
	Disagree	Count	15	11	26
		% within Received consultation from government	57.7%	42.3%	100.0%
		% within Biological control agents (BCA)	48.4%	37.9%	43.3%
		% of Total	25.0%	18.3%	43.3%
	Undecided	Count	3	0	3
		% within Received consultation from government	100.0%	0.0%	100.0%
		% within Biological control agents (BCA)	9.7%	0.0%	5.0%
		% of Total	5.0%	0.0%	5.0%
	Agree	Count	2	4	6
		% within Received consultation from government	33.3%	66.7%	100.0%
		% within Biological control agents (BCA)	6.5%	13.8%	10.0%
		% of Total	3.3%	6.7%	10.0%

Total	Count	31	29	60
	% within Received consultation from government	51.7%	48.3%	100.0%
	% within Biological control agents (BCA)	100.0%	100.0%	100.0%
	% of Total	51.7%	48.3%	100.0%

Received consultation from chemical companies * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Received consultation from chemical companies	Strongly Disagree	Count	3	3	6
		% within Received consultation from chemical companies	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	10.0%	10.3%	10.2%
		% of Total	5.1%	5.1%	10.2%
	Disagree	Count	8	7	15
		% within Received consultation from chemical companies	53.3%	46.7%	100.0%
		% within Biological control agents (BCA)	26.7%	24.1%	25.4%
		% of Total	13.6%	11.9%	25.4%
	Undecided	Count	1	2	3
		% within Received consultation from chemical companies	33.3%	66.7%	100.0%
		% within Biological control agents (BCA)	3.3%	6.9%	5.1%
		% of Total	1.7%	3.4%	5.1%
	Agree	Count	15	15	30
		% within Received consultation from chemical companies	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	50.0%	51.7%	50.8%
		% of Total	25.4%	25.4%	50.8%
	Strongly Agree	Count	3	2	5
		% within Received consultation from chemical companies	60.0%	40.0%	100.0%
		% within Biological control agents (BCA)	10.0%	6.9%	8.5%
		% of Total	5.1%	3.4%	8.5%
Total		Count	30	29	59
		% within Received consultation from chemical companies	50.8%	49.2%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	50.8%	49.2%	100.0%

Received consultation from insectary companies * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Received consultation from insectary companies	Strongly Disagree	Count	0	4	4
		% within Received consultation from insectary companies	0.0%	100.0%	100.0%
		% within Biological control agents (BCA)	0.0%	13.8%	6.8%
		% of Total	0.0%	6.8%	6.8%
	Disagree	Count	5	11	16
		% within Received consultation from insectary companies	31.3%	68.8%	100.0%
		% within Biological control agents (BCA)	16.7%	37.9%	27.1%
		% of Total	8.5%	18.6%	27.1%
	Undecided	Count	1	2	3
		% within Received consultation from insectary companies	33.3%	66.7%	100.0%
		% within Biological control agents (BCA)	3.3%	6.9%	5.1%
		% of Total	1.7%	3.4%	5.1%
	Agree	Count	21	11	32
		% within Received consultation from insectary companies	65.6%	34.4%	100.0%
		% within Biological control agents (BCA)	70.0%	37.9%	54.2%
		% of Total	35.6%	18.6%	54.2%

	Strongly Agree	Count	3	1	4
		% within Received consultation from insectary companies	75.0%	25.0%	100.0%
		% within Biological control agents (BCA)	10.0%	3.4%	6.8%
		% of Total	5.1%	1.7%	6.8%
Total		Count	30	29	59
		% within Received consultation from insectary companies	50.8%	49.2%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	50.8%	49.2%	100.0%

Received consultation from other companies * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Received consultation from other companies	Strongly Disagree	Count	2	0	2
		% within Received consultation from other companies	100.0%	0.0%	100.0%
		% within Biological control agents (BCA)	6.9%	0.0%	3.4%
		% of Total	3.4%	0.0%	3.4%
	Disagree	Count	8	4	12
		% within Received consultation from other companies	66.7%	33.3%	100.0%
		% within Biological control agents (BCA)	27.6%	13.3%	20.3%
		% of Total	13.6%	6.8%	20.3%
	Undecided	Count	3	4	7
		% within Received consultation from other companies	42.9%	57.1%	100.0%
		% within Biological control agents (BCA)	10.3%	13.3%	11.9%
		% of Total	5.1%	6.8%	11.9%
	Agree	Count	13	20	33
		% within Received consultation from other companies	39.4%	60.6%	100.0%
		% within Biological control agents (BCA)	44.8%	66.7%	55.9%
		% of Total	22.0%	33.9%	55.9%
	Strongly Agree	Count	3	2	5
		% within Received consultation from other companies	60.0%	40.0%	100.0%
		% within Biological control agents (BCA)	10.3%	6.7%	8.5%
		% of Total	5.1%	3.4%	8.5%
Total		Count	29	30	59
		% within Received consultation from other companies	49.2%	50.8%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	49.2%	50.8%	100.0%

Government provides monitoring services * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Government provides monitoring services	Strongly Disagree	Count	13	10	23
		% within Government provides monitoring services	56.5%	43.5%	100.0%
		% within Biological control agents (BCA)	43.3%	35.7%	39.7%
		% of Total	22.4%	17.2%	39.7%
	Disagree	Count	14	13	27
		% within Government provides monitoring services	51.9%	48.1%	100.0%
		% within Biological control agents (BCA)	46.7%	46.4%	46.6%
		% of Total	24.1%	22.4%	46.6%
	Undecided	Count	2	1	3
		% within Government provides monitoring services	66.7%	33.3%	100.0%
		% within Biological control agents (BCA)	6.7%	3.6%	5.2%
		% of Total	3.4%	1.7%	5.2%

	Agree	Count	1	3	4
		% within Government provides monitoring services	25.0%	75.0%	100.0%
		% within Biological control agents (BCA)	3.3%	10.7%	6.9%
		% of Total	1.7%	5.2%	6.9%
	Strongly Agree	Count	0	1	1
		% within Government provides monitoring services	0.0%	100.0%	100.0%
		% within Biological control agents (BCA)	0.0%	3.6%	1.7%
		% of Total	0.0%	1.7%	1.7%
Total		Count	30	28	58
		% within Government provides monitoring services	51.7%	48.3%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	51.7%	48.3%	100.0%

Chemical companies provides monitoring services * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Chemical companies provides monitoring services	Strongly Disagree	Count	10	8	18
		% within Chemical companies provides monitoring services	55.6%	44.4%	100.0%
		% within Biological control agents (BCA)	32.3%	30.8%	31.6%
		% of Total	17.5%	14.0%	31.6%
	Disagree	Count	15	12	27
		% within Chemical companies provides monitoring services	55.6%	44.4%	100.0%
		% within Biological control agents (BCA)	48.4%	46.2%	47.4%
		% of Total	26.3%	21.1%	47.4%
	Undecided	Count	3	4	7
		% within Chemical companies provides monitoring services	42.9%	57.1%	100.0%
		% within Biological control agents (BCA)	9.7%	15.4%	12.3%
		% of Total	5.3%	7.0%	12.3%
	Agree	Count	3	1	4
		% within Chemical companies provides monitoring services	75.0%	25.0%	100.0%
		% within Biological control agents (BCA)	9.7%	3.8%	7.0%
		% of Total	5.3%	1.8%	7.0%
	Strongly Agree	Count	0	1	1
		% within Chemical companies provides monitoring services	0.0%	100.0%	100.0%
		% within Biological control agents (BCA)	0.0%	3.8%	1.8%
		% of Total	0.0%	1.8%	1.8%
Total		Count	31	26	57
		% within Chemical companies provides monitoring services	54.4%	45.6%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	54.4%	45.6%	100.0%

Insectary companies provides monitoring services * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Insectary companies provides monitoring services	Strongly Disagree	Count	8	8	16
		% within Insectary companies provides monitoring services	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	26.7%	29.6%	28.1%
		% of Total	14.0%	14.0%	28.1%
	Disagree	Count	15	11	26
		% within Insectary companies provides monitoring services	57.7%	42.3%	100.0%
		% within Biological control agents (BCA)	50.0%	40.7%	45.6%
		% of Total	26.3%	19.3%	45.6%

	Undecided	Count	3	5	8
		% within Insectary companies provides monitoring services	37.5%	62.5%	100.0%
		% within Biological control agents (BCA)	10.0%	18.5%	14.0%
		% of Total	5.3%	8.8%	14.0%
	Agree	Count	4	2	6
		% within Insectary companies provides monitoring services	66.7%	33.3%	100.0%
		% within Biological control agents (BCA)	13.3%	7.4%	10.5%
		% of Total	7.0%	3.5%	10.5%
	Strongly Agree	Count	0	1	1
		% within Insectary companies provides monitoring services	0.0%	100.0%	100.0%
		% within Biological control agents (BCA)	0.0%	3.7%	1.8%
		% of Total	0.0%	1.8%	1.8%
Total		Count	30	27	57
		% within Insectary companies provides monitoring services	52.6%	47.4%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	52.6%	47.4%	100.0%

Other organosations provide monitoring services * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Other organosations provide monitoring services	Strongly Disagree	Count	2	3	5
		% within Other organozations provide monitoring services	40.0%	60.0%	100.0%
		% within Biological control agents (BCA)	6.9%	10.7%	8.8%
		% of Total	3.5%	5.3%	8.8%
	Disagree	Count	12	10	22
		% within Other organozations provide monitoring services	54.5%	45.5%	100.0%
		% within Biological control agents (BCA)	41.4%	35.7%	38.6%
		% of Total	21.1%	17.5%	38.6%
	Undecided	Count	2	5	7
		% within Other organozations provide monitoring services	28.6%	71.4%	100.0%
		% within Biological control agents (BCA)	6.9%	17.9%	12.3%
		% of Total	3.5%	8.8%	12.3%
	Agree	Count	9	7	16
		% within Other organozations provide monitoring services	56.3%	43.8%	100.0%
		% within Biological control agents (BCA)	31.0%	25.0%	28.1%
		% of Total	15.8%	12.3%	28.1%
	Strongly Agree	Count	4	3	7
		% within Other organozations provide monitoring services	57.1%	42.9%	100.0%
		% within Biological control agents (BCA)	13.8%	10.7%	12.3%
		% of Total	7.0%	5.3%	12.3%
Total		Count	29	28	57
		% within Other organozations provide monitoring services	50.9%	49.1%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	50.9%	49.1%	100.0%

Government, insectary companies and other organisation provides information * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Government insectary companies and other organisation provides information	Strongly Disagree	Count	1	8	9
		% within Government, insectary companies and other organization provides information	11.1%	88.9%	100.0%
		% within Biological control agents (BCA)	3.6%	27.6%	15.8%
		% of Total	1.8%	14.0%	15.8%
	Disagree	Count	12	6	18
		% within Government, insectary companies and other organization provides information	66.7%	33.3%	100.0%
		% within Biological control agents (BCA)	42.9%	20.7%	31.6%
		% of Total	21.1%	10.5%	31.6%
	Undecided	Count	4	5	9
		% within Government, insectary companies and other organization provides information	44.4%	55.6%	100.0%
		% within Biological control agents (BCA)	14.3%	17.2%	15.8%
		% of Total	7.0%	8.8%	15.8%
	Agree	Count	9	10	19
		% within Government, insectary companies and other organization provides information	47.4%	52.6%	100.0%
		% within Biological control agents (BCA)	32.1%	34.5%	33.3%
		% of Total	15.8%	17.5%	33.3%
	Strongly Agree	Count	2	0	2
		% within Government, insectary companies and other organization provides information	100.0%	0.0%	100.0%
		% within Biological control agents (BCA)	7.1%	0.0%	3.5%
		% of Total	3.5%	0.0%	3.5%
Total		Count	28	29	57
		% within Government, insectary companies and other organization provides information	49.1%	50.9%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	49.1%	50.9%	100.0%

Government subsidized citrus farm * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Government subsidised citrus farm	Strongly Disagree	Count	18	18	36
		% within Government subsidized citrus farm	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	60.0%	69.2%	64.3%
		% of Total	32.1%	32.1%	64.3%
	Disagree	Count	10	8	18
		% within Government subsidized citrus farm	55.6%	44.4%	100.0%
		% within Biological control agents (BCA)	33.3%	30.8%	32.1%
		% of Total	17.9%	14.3%	32.1%
	Agree	Count	2	0	2
		% within Government subsidized citrus farm	100.0%	0.0%	100.0%
		% within Biological control agents (BCA)	6.7%	0.0%	3.6%
		% of Total	3.6%	0.0%	3.6%
Total		Count	30	26	56
		% within Government subsidized citrus farm	53.6%	46.4%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	53.6%	46.4%	100.0%

Don't get any help except information * Biological control agents (BCA) Crosstabulation

			Biological control agents (BCA)		Total
			BCA user	BCA non-user	
Don't get any help except information	Strongly Disagree	Count	4	2	6
		% within Don't get any help except information	66.7%	33.3%	100.0%
		% within Biological control agents (BCA)	13.8%	6.5%	10.0%
		% of Total	6.7%	3.3%	10.0%
	Disagree	Count	4	4	8
		% within Don't get any help except information	50.0%	50.0%	100.0%
		% within Biological control agents (BCA)	13.8%	12.9%	13.3%
		% of Total	6.7%	6.7%	13.3%
	Undecided	Count	2	6	8
		% within Don't get any help except information	25.0%	75.0%	100.0%
		% within Biological control agents (BCA)	6.9%	19.4%	13.3%
		% of Total	3.3%	10.0%	13.3%
	Agree	Count	14	11	25
		% within Don't get any help except information	56.0%	44.0%	100.0%
		% within Biological control agents (BCA)	48.3%	35.5%	41.7%
		% of Total	23.3%	18.3%	41.7%
	Strongly Agree	Count	5	8	13
		% within Don't get any help except information	38.5%	61.5%	100.0%
		% within Biological control agents (BCA)	17.2%	25.8%	21.7%
		% of Total	8.3%	13.3%	21.7%
Total		Count	29	31	60
		% within Don't get any help except information	48.3%	51.7%	100.0%
		% within Biological control agents (BCA)	100.0%	100.0%	100.0%
		% of Total	48.3%	51.7%	100.0%