Student Scholarship: ‘Orcharding the Future: the influence of temperature on pome fruit flowering across Australia’

The University of Melbourne

Project Number: AP13023

AP13023

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AP13023 Student Scholarship: ‘Orcharding the Future: the influence of temperature on pome fruit flowering across Australia’

Milestone Report 190

February 2015

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Milestone requirements for this reporting period:

1. Student mini-thesis (10,000-20,000 words).
   Attached separately.
2. Results presented in a seminar organised by the University of Melbourne.
   Completed. Chaired by Dr Natalie Jamieson on 7th October 2014 at Babel lecture theatre, the University of Melbourne.
3. Development of a summary document of current and future pathways to enable greater connection of the apple and pear industry to students at the University of Melbourne.
   This document.

Horticultural Industry Participation in Melbourne University Student Programs

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1 Introduction

Building and maintaining research capacity in Australian perennial horticulture is a critical future need for industry. To foster quality researchers, many other Australian agricultural industry bodies have developed standing arrangements to recruit students via scholarship opportunities. This approach has several benefits including increasing research capacity, in-kind utilisation of university facilities and expertise and production of high quality research at very low cost. Recently, the apple and pear industry recognised this benefit through the support of a Master's student scholarship (project AP13023) to investigate flowering patterns of different apple bud types across Australia.

This one-off project illustrated one approach to increase research capacity in horticulture. However, a more strategic involvement with the tertiary education sector is required to build capacity to ensure longevity and continual advancement of horticultural research in Australia.

This report aims to explore options for greater industry involvement in existing Melbourne University programs and outlines avenues for industry to support students. Barriers to increasing participation in horticultural science at the tertiary level will also be discussed.

2 Student Focus

Prior to discussing industry opportunities to interact with students it is important to appreciate all Melbourne University courses have a sharp focus on student learning outcomes. Industry interaction is expected to enhance and add to the student experience with the student remaining the centre of importance. Below is an excerpt highlighting the university's commitment to student learning outcomes:

> *"The University of Melbourne provides students with a rich and varied learning experience characterised by an atmosphere of intellectual excitement, an intensive research culture, a commitment to global engagement, clear academic expectations and standards…"*

Following this commitment to student learning, University academic standards and assessment requirements must be upheld for all courses, including those involving industry. These standards set expectations for both industry and students.

Melbourne University provides various course options in which industry can participate in and benefit from. The following sections outline existing structures which industry can connect into to increase student exposure to, and participation in, the horticultural industry. These have been separated into 'traditional' and 'contemporary' courses to highlight both well-known course structures and more recent advances in teaching at Melbourne University.

3 Traditional Student Courses

A mainstay of research training within the university sector is the progression from an honours research year, awarded at the undergraduate level, through to graduate research at masters and PhD levels. These three types of student research represent more commonly known opportunities for industry to interact with students.

Common across each of these three types of student research is an academic supervisor, or supervisors, who act to guide and develop the student in the fundamentals of conducting research. Topics of student research projects tend to either be selected by the student from a list of potential options provided by perspective supervisors or developed by the student. Commonly, honours students will select a project proposed by faculty academics whilst masters and PhD students more often develop and/or negotiate their own project topics.

Students undertaking research programs are expected to dedicate 40 hours per week full-time or 20 hours per week part-time to their studies. Eligibility into research programs requires high academic standard, usually at least a H2A (75-79%) average in previous studies. Agreement to supervise from a suitable academic supervisor(s) is additionally required for enrolment.

3.1 Honours

This is a one year full-time course, usually running in-line with the academic calendar (March – October), although mid-year offerings are also possible. An appropriate undergraduate degree is required for entry and honours is awarded at the undergraduate level. For many students this is their first significant research project.

In the Faculty of Veterinary and Agricultural Sciences (FVAS), honours students are required to complete both a coursework and research component with the research component a greater proportion of the grade.

Below is an excerpt of the expectations of the research component for honours students within FVAS. Of particular note is the inclusion of industry collaboration as a potential benefit.

> *Students will select a project from a list formulated by supervisors through the Honours Research Project subject coordinator.* ***Some of these projects may be offered in collaboration with industry, and collaborating institutions****. Project proposals detailing the experimental plan and a literature review will be presented to the Honours Panel orally and in writing about 2 months after commencement for discussion and approval prior to commencing experimental work. The proposal is assessed and is worth 10% of the final mark.*
>
> *Students will be required to present seminars on both their project proposal and the outcomes of their research. The expected length of the thesis (including references) is 15 000 - 20 000 words (approximately 50 A4 pages).*

Further information regarding the honours program:

http://fvas.unimelb.edu.au/study/courses/b-ag-honours/overview

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3.2 Master of Philosophy (MPhil)

This is a two year full-time course, with entry possible at any stage in the year. An undergraduate degree is a requirement for entry and MPhil is a graduate qualification. MPhil is a research only degree with no prescribed coursework component.

Unlike honours, maters students tend to be independent of formal university course structure with supervisors and the faculty and/or university student centres providing required support.

Below is an excerpt of the expectations of MPhil students within FVAS.

> *Candidates are expected to meet regularly with their supervisor(s) and to present their work in the Faculty's research seminar program. They are assisted to participate in relevant national or international conferences. A thesis is submitted in fulfilment of the degree.*
>
> *The normal thesis length is 30,000-40,000 words, exclusive of words in tables, maps bibliographies and appendices. Footnotes are included as part of the word limit.*

Further Information:

http://fvas.unimelb.edu.au/study/courses/master-of-philosophy-agriculture/overview

3.3 Doctor of Philosophy (PhD)

This is a three year full time course, with entry possible at any time during the year. An undergraduate degree with honours or a masters degree is a requirement for entry and PhD which is a graduate qualification. PhD is a research only degree with no prescribed coursework component.

Similarly to masters students, PhD students are supported by supervisors (usually a minimum of two) and the faculty and/or university student centres.

Below is an excerpt of the expectations of PhD students within FVAS.

> *The PhD thesis is a careful, rigorous and sustained piece of work demonstrating that a research 'apprenticeship' is complete and the holder is admitted to the community of scholars in the discipline.*
>
> *In scope, the PhD thesis differs from a research masters thesis, chiefly by its deeper and more comprehensive treatment of the chosen subject. It is written succinctly, in English, unless approval has been given for the thesis to be written in a language other than English.*
>
> *The normal length of a PhD thesis is 80,000 words, exclusive of words in tables, maps, bibliographies and appendices. Footnotes are included as part of the word limit. The thesis should not exceed 100,000 words (or equivalent), without special approval from the Research Higher Degrees Committee.*

Further information regarding the PhD program:

http://fvas.unimelb.edu.au/study/courses/doctor-of-philosophy-agriculture/overview

4 Contemporary Student Courses

The traditional honours-masters-PhD research student pathway has been established for some time. More recently, Melbourne University has developed new courses and subjects that provide additional and innovative pathways for industry involvement. Table 1 in the Appendix provides a summary of subjects currently offered by FVAS which include possible industry involvement.

Within the Bachelor of Agriculture, 2nd year students are able to participate in an 'Industry Internship' subject (AGRI20024). In this subject, it is expected that students are embedded within an industry for a total of 80 hours. Similarly, 3rd year students are able to enrol in 'Industry Project' or 'Research Project' subjects (AGRI30001/ AGRI30002/ AGRI30005/ AGRI30006 and ENST30002). These are small research projects individually tailored to each student and each student is supervised by an academic in the faculty.

Industry involvement with the above mentioned undergraduate subjects may require development of an appropriate project in consultation with the subject coordinator and academic supervisor, inclusion of a student into industry operations and in some instances, provision of an assessment of the student's performance.

In the graduate space, since the inception of the 'Melbourne Model', masters by coursework programs are now widely offered by Melbourne University (for FVAS masters programs http://fvas.unimelb.edu.au/study/courses).

These masters programs offer students specialised areas of study and attract both domestic and international students. Of particular relevance to industry is the option for students to undertake a research component within their course (AGRI90064/AGRI90070/ AGRI90065/ AGRI90072). The project AP13023 was conducted with a student who enrolled in a research project subject within a masters by coursework program. These are detailed in Table 1 in the Appendix. These research projects can comprise of an eighth or a quarter of the masters degree. Timeframes vary but tend either run for a single semester or yearlong and are more closely aligned to university teaching calendars than MPhil or PhD research projects. Frequently, perspective supervisors will provide a list of potential projects and students approach the academic directly. Research project coordinators run the program with some additional seminars offered to enhance student's research experience.

Another option at the graduate level for industry involvement is the 'Industry Internship' (AGRI90076 and AGRI90078) subject. In this subject the student is embedded within an industry and assessment centres on the internship experience and interaction with staff.

5 Industry Participation

Horticulture and APAL in particular are uniquely positioned to take advantage of FVAS subjects and courses that are already operational. The APAL head office is in close proximity to the Parkville campus meaning internships would be logistically simple. Further, discussion with academic supervisors and students undertaking industry relevant research projects would be similarly easy to coordinate.

Melbourne University's Dookie campus is situated in the Goulburn Valley area, the major pome fruit growing region in Australia. Both internship and research project options could take advantage of both the facilities at Dookie and close industry location. Finally, the Victorian Government has established a Horticulture Centre of Excellence[1] at the Tatura site, nearby to Dookie. The University of Melbourne has contributed to the establishment the centre. This centre may provide opportunities for students to connect with University academics, government scientists and industry.

The university and FVAS in particular are increasingly focused on producing work ready graduates. Industry internships are important in achieving this and FVAS has outlined the potential benefits to host organisations (http://fvas.unimelb.edu.au/research/what-fvas-offers-the-host-organisation).

[1] http://www.depi.vic.gov.au/agriculture-and-food/horticulture/horticulture-centre-of-excellence

5.1 Industry Interaction: Traditional Courses

5.2 Scholarships

For research based courses (honours, MPhil and PhD) direct support from industry is a clear option. Several other industry bodies offer student based scholarship programs for these research courses (for example AGWA, Sugar and MLA). These scholarship opportunities offer financial support through a stipend, either in full or as a top-up to government scholarships, and operational funds. Some industries additionally organise workshops and networking opportunities for their supported students.

These scholarships are awarded on student merit, likelihood of ongoing involvement in the industry and project topic alignment to industry research and development goals. These are not tied to particular universities and the industry bodies retain the right to award as many or as few (including zero) scholarships as desired. These programs are particularly beneficial to research students providing access and exposure to industry. In supporting these students, industry benefits from research in an identified priority area at low cost and increases research capacity in their sector. The ongoing running of such programs by several industries is indicative of their success.

Australian Grape and Wine Authority (AGWA) provides a relevant example of an industry based scholarship program[2]. AGWA offers the following funding opportunities to students:

	Length	**Stipend**	**Operational**
PhD (full time) with APA*	3 years	supplementary funding (including that received through the APA or equivalent) up to $30,000 (GST exclusive) per annum	up to $10,000 (GST exclusive) per annum
Masters (full time) with APA*	2 years	supplementary funding (including that received through the APA or equivalent) up to $30,000 (GST exclusive) per annum	up to $10,000 (GST exclusive) per annum
PhD (full time)	3 years	up to $30,000 (GST exclusive) per annum	up to $10,000 (GST exclusive) per annum
Masters (full time)	2 years	up to $30,000 (GST exclusive) per annum	up to $10,000 (GST exclusive) per annum
Honours	1 year	up to $4,000 (GST exclusive)	up to $2,000 (GST exclusive)

*APA is an Australian Postgraduate Award. This is a stipend provided by the Australian Government see: https://studenteforms.app.unimelb.edu.au/apex/f?p=153:2:0:::2:P2_ID:50

5.3 Research Student Engagement

In addition to direct support of research students, industry can engage with research students in several other ways:

- Offer student scholarships to attend industry conferences.
- Run a research student workshop for existing students in horticulture, in combination with industry conferences or as a standalone event.

[2] http://research.agwa.net.au/agwa-opens-first-round-of-applications-for-post-graduate-scholarships/

- Consult with horticultural academics at the university to highlight research areas of focus which can then be suggested to perspective students (e.g. see http://fvas.unimelb.edu.au/research/projects).
- Offer student sponsorship to relevant international conferences.
- Establish a network for research students, and perhaps postdoctoral researchers, to communicate industry opportunities and news.
- Participate in/ organise end of year career days at the university directed towards third year Bachelor of Agriculture students.

5.4 Industry Interaction: Contemporary Courses

To take advantage of the internship options available through the university, industry will need to consult with relevant subject coordinators to develop appropriate student opportunities. To provide students with a valuable experience, opportunities within the industry body, with growers and consultants should all be considered. Facilitation in finding appropriate placement businesses would be a valuable role for industry. These may need to be modified dependent on the student, their experience, future aspirations and university assessment standards.

For research project based subjects, consultation with the university and appropriate academics to outline key areas of research interest is needed. To encourage student participation in horticultural based research, scholarship opportunities for these smaller research projects may prove helpful. Indeed the support provided via industry through project AP13023 was pivotal in sourcing a student for the project.

Pre-formulation of several options for industry placements and small defined research projects as relevant to industry will be helpful in sourcing appropriate students. This will mean that when a student wishes to be involved in an internship or project, several options will already be available and university administration timelines should be able to be met.

6 Other opportunities

Further to direct interaction with students via research scholarships and provision of opportunities through specific subjects, the horticulture industry can take advantage of other existing programs to enhance research capacity beyond student support.

For example, the VESKI organisation, funded by the Victorian Government aims to build strategic partnerships and collaborations with business, academia and philanthropic organisations. Through these relationships VESKI's vision is to foster innovation in the economy. Two programs of particular note are:

1. Inspiring women industry internships[3]. Aimed to support, advance and inform Victorian women through partnerships with government, industry and academia. Combining this opportunity with existing university subjects appears viable and provides an important pathway for more women to enter horticultural research.

[3] http://www.veski.org.au/inspiring-women-internships

2. Postdoctoral research fellowships[4]. Aimed at postgraduates these fellowships require two years research at an international organisation and a final year in Victoria. Promoting such opportunities to recent PhD horticultural graduates and supporting their applications would be a cost effective option to increase research and international collaboration within the horticultural industry.

Other opportunities may be developed either regarding current university programs, future options or other state and federal run programs. FVAS has appointed an Associate Dean for Engagement and Partnerships (Associate Professor Ruth Nettle - ranettle@unimelb.edu.au) for further development of engagement opportunities.

7 Barriers

There are many barriers present in aiming to foster stronger ties with University of Melbourne students to enhance research capacity in Australia's horticultural industry:

- Attracting students to participate in horticultural research and internships.
    - Sourcing and securing appropriate students into research and internships can be difficult, even with funding opportunities.
    - Greater promotion of the horticulture industry throughout undergraduate degrees may assist as well as positive feedback to the student body from those who do take up projects or internships.
- Academic supervisor availability.
    - For most of the options outlined, an academic supervisor is required. Academics with appropriate expertise or sufficient time may not always be available.
    - Negotiation for non-university supervisors may be a viable option to alleviate some of the supervision burden. For instance, many Victorian Government scientists have appropriate academic credentials and could act as supervisors.
- International student access to awards and scholarships.
    - International students pay larger fees than domestic students and are often ineligible for Australian scholarship opportunities (e.g. APA). This can pose a significant financial barrier to undertaking further studies in Australia.
    - Under the current system this will likely persist. Special scholarship and university positions for international students in key research areas as identified by industry would assist to alleviate this barrier.
- Realistic operational funds.
    - For research projects within the masters by coursework program, a modest operational budget can be applied for through the university. If the student is required to travel to the regions for field work or interaction with industry it is likely the student would bear much of the cost. This is not a tenable option.
    - Negotiated budgets for horticultural students with a modest top up from industry/ placement organisations/ horticultural centre of excellence may be sufficient to overcome this barrier.

[4] http://www.veski.org.au/VPRF

- Post degree career options.
    - Encouragement of students into horticultural research is the first and necessary step to enhance research capacity in the industry. Substantial challenges face graduates in securing employment in the Australian industry after graduation, which is required to consolidate and grow research capacity.
    - Government opportunities, both federally and in state departments, are limited with many agencies several years into recruitment freezes. University places for graduates tend to be connected to external funding and are short term contracts. Within industry greater options may be present although regional locales can be a deterrent. International opportunities may further add difficulties in retaining graduates in Australia.
    - Overseas opportunities are often desired by new graduates to enhance their academic credentials. Programs such as VESKI's postdoctoral scholarship scheme allow for an international experience but ensure that knowledge is retained within Australia. Conversely, international graduates could be actively recruited as they similarly seek global academic enrichment.

8 Summary

Industry support of a masters by coursework student's research project (AP13023) proved a successful training opportunity in encouraging greater student participation in research in the apple and pear industry. The student produced a high quality research thesis (attached). Support from industry allowed the student to travel to the Goulburn Valley to better understand the industry and participate in the International Horticultural Congress held in Brisbane in August 2014. These opportunities in combination with a stimulating project topic spurred the student to seek out PhD options in horticulture. Unfortunately, as an international student, ineligibility for financial support proved to a barrier to further studies in Australia.

In a broader sense, the horticultural industry has several options to better connect with university training of students to increase capacity in horticulture. For traditional research courses (honours, MPhil, PhD), three key pathways are evident. Firstly, the development of industry awarded scholarships for projects relevant to industry priorities. This would bring horticulture in line with many other Australian industry bodies. Secondly, greater connection to university academics in the development of potential research project topics. Thirdly, incorporation of research student workshops, and sponsored attendance, to industry conferences.

Newer university courses, including shorter research projects and internships for undergraduate and coursework graduate students provide an opportunity for greater industry involvement. Engagement with university course and subject coordinators to negotiate opportunities within horticulture for students will increase graduate knowledge in the industry and highlight career pathways for students. Noting that some industry commitment to contribute to student learning outcomes will be required.

Finally, some barriers to greater linkages to university students exist. Student recruitment may be difficult as well as sufficient availability of academic supervisors. Eligibility of international students for scholarship opportunities can be counterproductive. Finally, insecure future research pathways after graduation is also a barrier to creating a stable base of horticultural researchers in Australia with skilled students forced to seek employment in other countries, industries or fields.

Appendix

Table 1 FVAS subject descriptions relevant for industry involvement.

Subject Code	Subject Name	Teaching level	Overview	Coordinator
AGRI20024	Industry Internship	Undergraduate	• 2nd year • Semester 1 and 2 • Placement to be equivalent to 2 weeks full time employment or a total of 80 hours. Students may undertake this one day per week during semester (10 days) or more intensively eg. 3 days/week for 3 weeks during the mid-year break if enrolled in an intensive subject. • This subject involves completion of a minimum of 80 hours work placement integrating academic learning, employability skills and attributes and an improved knowledge of organisations, workplace culture and career pathways. The placement is supplemented by pre- and post-placement classes designed to introduce skills for developing, identifying and articulating employability skills and attributes and linking them to employer requirements. The placement should draw on specific discipline skills associated with the course of enrolment. Pre-placement seminars will also include consideration of career planning and professional skills. Students are responsible for identifying a suitable work placement, by Week 1 of semester, with support from Student Programs staff. In the semester prior to your placement you should attend Careers & Employment (C&E) employment preparation seminars and workshops and access other C&E resources to help you to identify potential host organisations (http://www.services.unimelb.edu.au/careers/). You will need to commence your approaches to organisations at least 4 weeks before the placement. More information is available in the Subject Guide. Placements must be approved by the Subject	Ros Gall +61 3 5833 9226 rosgall@unimelb.edu.au

			Coordinator. If you have problems finding a placement you should approach the Subject coordinator. On completion of the subject, students will have completed and reported on a course-related project in a workplace. They will also have enhanced employability skills including communication, interpersonal, analytical and problem-solving, organisational and time-management, and an understanding of career planning and professional development. • Assessment: 1000 word career case study based on an information interview with an employee in your placement (25%), 2000 word essay on the placement experience (50%), 80 hours of satisfactory work placement (hurdle), individual or team presentation (10-15 mins) on a work related or discipline specific topic (to be presented in post placement - 25%), attendance at a minimum of four of six of the seminar series (hurdle).	
AGRI30001/ AGRI30002/ AGRI30005/ AGRI30006	Industry Project	Undergraduate	• 3rd year • Yearlong or by semester, Dookie or Parkville • Contact Hours: Twelve hours of lectures, plus class contact and seminars as arranged Total Time Commitment: 340 hours • This subject involves the definition and development of an industry-related project, and develops skills in project management, problem solving and planning and reporting investigations. The topic involves or draws on a specific and defined industry issue, and may be developed in relation to a period of time spent in industry placement or previously or concurrently selected elective subjects, applying the knowledge gained in these subjects to a real resource-based industry investigative problem. The project may relate to an applied scientific, economic or sociological or managerial topic, and the work will involve close collaboration between student, academic staff and industry advisors. Students work interactively with a supervisor to define their	Dr. Graham Brodie +61 3 5833 9273 grahamb@unimelb.edu.au

			particular project. Each student prepares a detailed literature review and project proposal that places their project into context and includes methodology and approach, and covers the relevant background. A pass mark in the proposal assignment is a hurdle requirement for continuation of the subject. This involves establishing base knowledge in the relevant area; definition of the issue; analysis of the approaches normally taken by industry to address such problems and the degree of success normally attained. A final report is submitted by each student and an oral presentation is presented at completion to an audience including industry members. These detail development of suitable investigative strategies and methodologies and the analysis of results or outcomes in a practical context. Students meet regularly with their supervisor for guided, interactive discussion on their projects. Students are required to attend/view online a series of seminars delivered on project design, management and communication strategies. • Assessment: Project literature review and proposal 2000 words, (30%), final written report 5000 words (50%), 10 minute oral presentation (20%)	
ENST30002	Research Project	Undergraduate	• 3rd year • Semester 1 or 2 • Contact Hours: Distribution of time between specific tasks will be decided in negotiation with the supervisor, but an overall weekly commitment of 10 hours per week is expected. Total Time Commitment: 170 hours • An individual program of supervised research in which the student designs a research project, in consultation with the supervisor, carries out and presents the results of the project. Detailed requirements are to be negotiated with the supervisor and the subject coordinator. Each student will receive feedback on their progress through ongoing consultation with their supervisor. • Assessment: Written report (including data presented in a variety of formats up to the equivalent of 3500 words) - 70%, oral report (10	Dr. Sabine Tausz-Posch +61 3 5321 4140 sposch@unimelb.edu.au

			minutes) or poster presentation of equivalent preparation and presentation time - 15%, and supervisor assessment of research competence according to student's contribution to project design and implementation due towards the end of semester - 15%.	
AGRI90064/ AGRI90070	Minor research project	Graduate	• Graduate level • Semester 1 and/or 2 • Contact Hours: One hour per week class time, scheduled supervisor meetings plus individual project work. Meeting frequency / duration to be agreed with the project supervisor. Total Time Commitment: 170 hours • This subject enables students to conduct an original research topic under supervision, as approved by an academic project supervisor. • The content and extent of the project will be determined by a project supervisor in consultation with the student and subject coordinator. Students are strongly encouraged to initiate project ideas within existing networks or to identify a project topic of keen interest, through discussion with the Faculty staff, prior to subject commencement. The project represents a capstone subject and comprises a review of a body of relevant literature, together with a critical evaluation of research or experimental protocols, a modest original experiment, or limited exploration of a scientific problem, or an investigation into a problem using an approved methodology. Following an initial workshop to establish subject expectations, deliverables and skill base requirements, projects will generally involve regular meetings with their supervisor where students report on progress, difficulties and research plans. Other workshops will deliver skill development in oral and written report presentation. • Assessment: 1,500 word project proposal (30%). 5,000 - 10,000 word final report (50%). 15 minute oral presentation (20%).	Peter Mcsweeney +61 3 9035 5319 peterm1@unimelb.edu.au
AGRI90065/ AGRI90072	Major research project	Graduate	• Graduate level • Semester 1 and/or 2	Peter Mcsweeney +61 3 9035 5319

			• Contact Hours: One hour per week class time, scheduled supervisor meetings plus individual project work. Meeting frequency / duration to be agreed with the project supervisor. Total Time Commitment: 340 hours • This subject enables students to conduct an original research topic under supervision, as approved by an academic project supervisor. • Students are strongly encouraged to initiate project ideas within existing networks or to identify a project topic of keen interest, through discussion with Faculty staff, prior to subject commencement. The project represents a capstone subject and comprises a review of a body of relevant literature, together with a critical evaluation of research or experimental protocols, a modest original experiment, or limited exploration of a scientific problem, or an investigation into a problem using an approved methodology. Following an initial workshop to establish subject expectations, deliverables and skill base requirements, projects will generally involve regular meetings with their supervisor where students report on progress, difficulties and research plans. Other workshops will deliver skill development in oral and written report presentation. • Assessment: Project Proposal (10%) 1,500 words. 15 minute Oral Presentation (15%). Final Report (75%) 10,000 - 20,000 words.	peterm1@unimelb.edu.au
AGRI90076	Industry Internship	Graduate	• Graduate level • Semester 1 or 2 • Placement to be equivalent to 2 weeks full time employment or a total of 80 hours. Students may undertake this one day per week during semester (10 days) or more intensively e.g. 3 days/week for 3 weeks during the mid-year break if enrolled in an intensive subject. This is to be negotiated with the placement supervisor and the student.	Ros Gall +61 3 5833 9226 rosgall@unimelb.edu.au

			• Contact Hours: Two six-hour workshops (summer term only) plus 80 hours industry placement; OR six two-hour seminars during semester plus 80 hours placement. Total Time Commitment: 170 hours. • This subject involves completion of a minimum 80 hours work placement integrating academic learning, employability skills and attributes and an improved knowledge of organisations, workplace culture and career pathways. The placement is supplemented by pre- and post-placement classes designed to introduce skills for developing, identifying and articulating employability skills and attributes and linking them to employer requirements. The placement should draw on specific discipline skills associated with the course of enrolment. Pre-placement seminars will also include consideration of career planning and professional skills. The placement is designed to be a standalone internship not integrated into any other subject. Students are responsible for identifying a suitable work placement, and will be assisted by Subject Coordinator and Internship Consultant. In the semester prior to your placement you should attend Careers & Employment (C&E) employment preparation seminars and workshops and access other C&E resources to assist you in identifying potential host organisations http://www.services.unimelb.edu.au/careers/. You will need to commence your approaches to organisations at least 4 weeks before the placement. More information is available in the Subject Guide. Placements must be approved by the Subject Coordinator or Internship Consultant. If you have problems finding a placement you should approach the Subject Coordinator or Internship Consultant. On completion of the subject, students will have completed and reported on a course-related project in a workplace. They will also have enhanced employability skills including communication, interpersonal, analytical and problem-solving, organisational and time-management, and an understanding of career planning and	

			professional development. • Assessment: 1500 word career case study based on an information interview with an employee in your placement (25%). 2500 word essay on the placement experience (50%). 80 hours of satisfactory work placement (hurdle). Individual or team presentation (10-15 mins) on a work related or discipline specific topic (25%).	
AGRI90078	Internship for Agricultural Sciences	Graduate	• Graduate level • Semester 1 or 2 • Contact Hours: 200 hours placement, 8 hours pre placement, 2 hours mid placement 4 hours post placement Total Time Commitment: 300 hours • This subject involves completion of an 200 hours of work placement, integrating academic learning, employability skills and attributes and an improved knowledge of organisations, workplace culture and career pathways. The placement is supplemented by pre- and post-placement classes designed to introduce skills for developing, identifying and articulating employability skills and attributes and linking them to employer requirements. The placement should draw on specific discipline skills associated with the course of enrolment. Pre-placement seminars will also include consideration of career planning and professional skills. Students are responsible for identifying a suitable work placement, by Week 1 of semester, with support from Student Programs staff. In the semester prior to your placement you should attend Careers & Employment (C&E) employment preparation seminars and workshops and access other C&E resources to help you to identify potential host organisations (http://www.services.unimelb.edu.au/careers/). You will need to commence your approaches to organisations at least 4 weeks before the placement. More information is available	

			in the Subject Guide. Placements must be approved by the Subject Coordinator. If you have problems finding a placement you should approach the Subject coordinator. On completion of the subject, students will have completed and reported on a course-related project in a workplace. They will also have enhanced employability skills including communication, interpersonal, analytical and problem-solving, organisational and time-management, and an understanding of career planning and professional development. • Assessment: A reflective journal of 2000 words including a log of hours worked (20%); a report or professional portfolio of 6000 words (60%); a 20 minute oral presentation on the internship placement (equivalent to approximately 2000 words), and host supervisor assessment report (20%); 200 hours of satisfactory work placement (hurdle)	

Further information search: https://handbook.unimelb.edu.au/faces/htdocs/user/search/SimpleSearch.jsp

THE UNIVERSITY OF MELBOURNE

Name: Marco Rodrigo Calderón Loor
Student number: 615288

Title of the research project: Orcharding the Future: The influence of temperature on Australian pome fruit flowering

Degree: Master of Environment

Subject: ENST70001 Environmental Research Project Long (50 points)

Supervisor: Dr Rebecca Darbyshire
Faculty: Melbourne School of Land and Environment

Co-Supervisor: Dr Heidi Parkes

Date: November 2014

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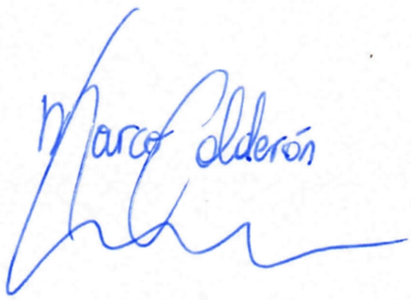
List of abbreviations

DOY	Day-of-year
IPCC	Intergovernmental Panel on Climate Change
IQR	Interquartile range
LGT	Length of the green tip phase
MAD	Median absolute deviation

Statement of original authorship

The work in this project was undertaken in partial fulfilment of the requirements of the University of Melbourne for the degree of Master of Environment. The views expressed are those of the author and might not reflect the views of the University of Melbourne, Office for Environmental Programs.



Dedication

A Carla a tí te lo dedico todo, mi tiempo, mi trabajo, mis alegrías, mi vida y mi amor. Gracias por ayudarme en estos tiempos sin tiempo, por levantarme cada vez y cuando, por sostenerme, abrazarme y arruncharme. Gracias porque nunca dejamos de soñar y de cumplir. A Martín a tí mi hijo también te dedico este trabajo, gracias por entenderme, enseñarme y quererme como tú lo haces. A ustedes dos por sera el hogar que nunca me abandona, que me motiva a ser mejor y que me trae por tantos caminos diferentes. La siguiente aventura será mejor aún!

De la misma manera este trabajo, y todo lo que ha significado lograrlo, está dedicado a las personas que me han ayudado a llegar hasta tan lejos, en sentido literal y figurado! Padres, hermanos, familia y amigos siempre están en mi corazón acompañandome en cada uno de mis pasos.

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A special thanks to my supervisor Dr. Rebecca Darbyshire for her guidance, patience, knowledge, kindness and motivation throughout this thesis process. Many thanks for allowing me to investigate about such an interesting field such as Horticulture. I would also like to thank my co-supervisor Dr. Heidi Parkes, her experience, clarity and knowledge were an invaluable help in all the stages of this project.

To all the people who helped me in different ways during this stage, but mainly I wish to thank my wife, Carla, and my friend Francisco (aka “el niño”) for helping me to polish this paper.

Last but not least a big special thank goes to my family, Carla and Martin, your support during this period have been crucial and without you this would not have meaning.

Abstract

Flowering development of pome fruit trees is dependent on local environmental conditions. The main driver in the timing of pome fruit flowering is temperature. However, understanding of the effect of temperature at an individual bud scale, is limited. The main purpose of this research was to investigate the differences in green tip timing, one of the earliest stages of flowering development, between bud types and potential temperature drivers. Changes in climate conditions may influence flowering timing potentially leading to a rise in the variability of fruit maturation, increasing harvesting costs as more picks are required. In addition, greater variability can potentially affect cross-pollination as varieties that pollinate each other may have different flowering at different times, limiting pollination potential. Furthermore, a better understanding of the relationships between temperature and individual bud behaviour will assist in assessments of future impacts of climate change on timing of flowering.

Data from three different types of buds from ‘Cripps Pink’ apple were collected for 2012 and 2013. The study sites, which represent different climatic conditions, were Applethorpe (QLD), Shepparton (VIC) and Manjimup (WA). Statistical tests were applied to the datasets to evaluate possible differences in green tip emergence between bud types, sites and years.

The results showed that on average spur buds were the first to burst at all sites. These were closely followed by terminal buds and then axillary buds. Comparing across locations buds in Shepparton and Applethorpe were first to burst in both years, and some days later those located in Manjimup. There were significant differences in the day-of-year when individual buds reached green tip between bud types, within and across sites. The length of the green tip phase also varied between buds, sites and years.

There was a consistent relationship between date of green tip and winter temperature. Cooler sites, Shepparton and Applethorpe, had the earliest dates of green tip while Manjimup experienced warmer winter seasons and the latest dates of green tip. Likewise, the warmer winter season, 2013, experienced a delay in the day-of-year when buds reached the green tip phase in all locations compared with 2012. Similarly, the length of the green tip phases was longer for 2013 than 2012.

The results from this study help to further elucidate the relationships between winter temperatures and green tip in ‘Cripps Pink’ apple. Understanding these relationships is essential for the identification of potential impacts that future climate change may have on apple production in Australia.

1 Introduction

Apples are a pome fruit grown on perennial deciduous trees. Cultivars can be grown commercially from the tropics to high latitude temperate regions (Wilkie et al. 2008), although most of the world's production comes from temperate zones. In Australia apples are grown in all six states (Figure 1.1), with Victoria the most productive zone (46% of total Australian production, 2002–2013) (APAL 2013). The apple industry is the second largest fruit industry in Australia (APAL 2013). The gross income of production for 2012 was approximately 567 AUD million. However, production can be significantly impacted by local climatic conditions. For instance, data from Australian Bureau of Statistics (2013) indicates a drop in apple production for 2011–2012, attributed to hailstorms that damaged the crops. This highlights the importance of understanding the impacts of environmental factors on the development of pome fruit, not only to account for reductions in yield, but also to propose appropriate adaptive measures for expected future changes in climate.

More than 10 varieties are grown in Australia, with Cripps Pink one of the most important as is the most cultivated in the country, about 60,500 tonnes in 2007–08 (Australian Bureau of Statistics 2011). Cripps Pink is the focus of this study. This variety was developed in Western Australia and is grown commercially known as Pink Lady® (Aussie apples 2012).

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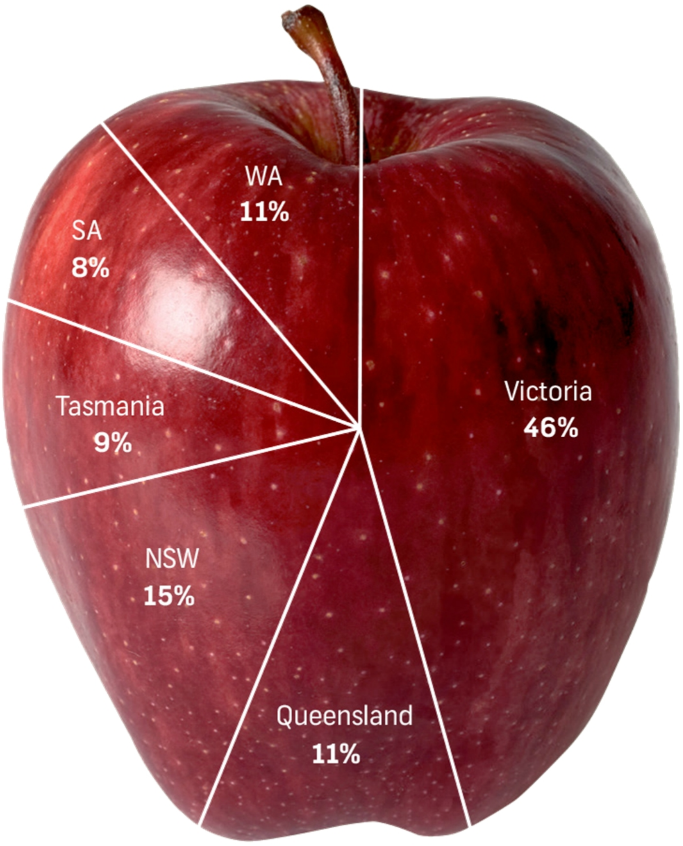


Figure 1.1: Apple production by state (APAL 2014).

1.1 Apple production cycle

An idealised seasonal cycle of apple fruit production is presented in Figure 1.2. Starting after harvest, the trees drop their leaves in order to prepare for winter. During winter the trees are characterised by a dormant state where any visible growth is suspended (Lang et al. 1987). To overcome this dormant phase, cumulative exposure to cold temperatures is required (Saure 1985). In early spring warm temperatures promote flowering, with green tip the first stage of the flowering phase. After flowering and pollination the fruit is set and then fruit maturation occurs up until harvest. This research is focused on the spring green tip component of the annual growth cycle of pome fruit trees. However, focusing on spring conditions alone may be insufficient in capturing the whole process. Hence, a description of two of the main processes related to green tip, winter dormancy and spring flowering, in the seasonal cycle of apples will be explored.

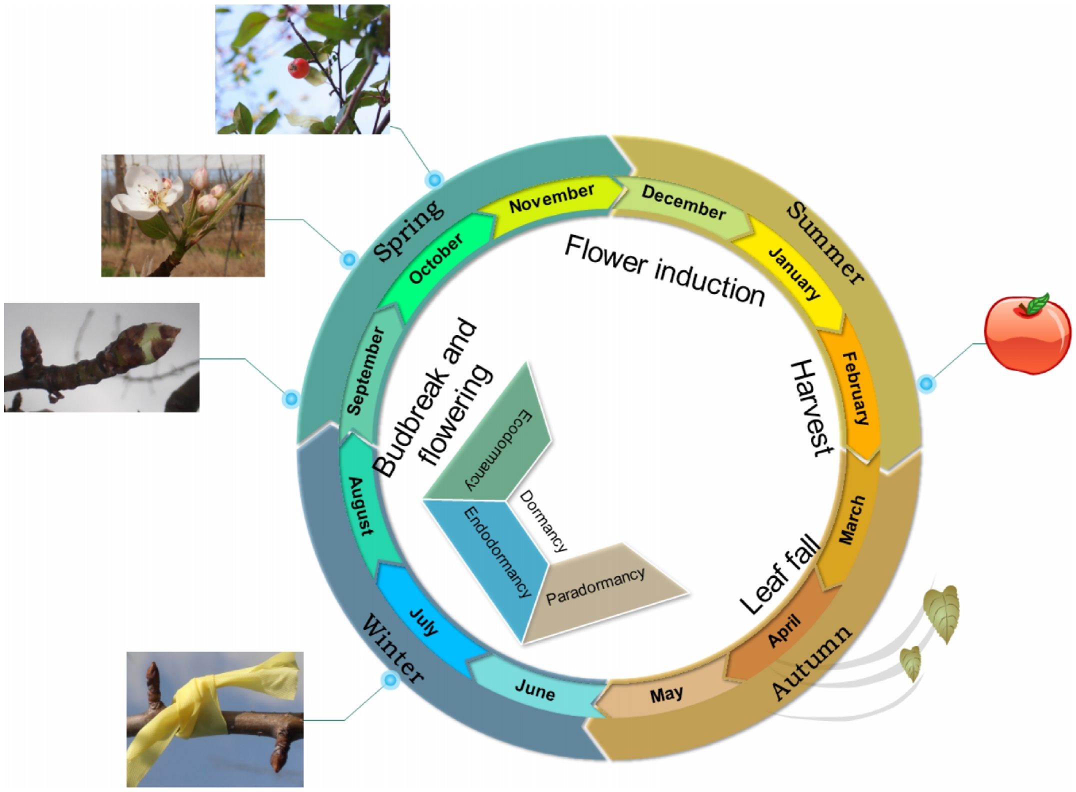


Figure 1.2: Southern hemisphere's seasonal cycle of pome fruit trees.

1.1.1 Winter Dormancy

Dormancy takes place after the trees have dropped their leaves in autumn and this stage enables the trees to survive unfavourable conditions during winter (Faust et al. 1997). Lang et al. (1987) defines dormancy as the period of temporary suspension of visible growth of any plant structure containing a meristem[1]. In deciduous fruit trees the buds can be dormant and still have growth in other parts of the tree (Martin 1991). However, only bud dormancy will be considered in this research[2].

The dormancy process of pome fruit buds in temperate regions, like southern Australia, can be differentiated in three stages depending on the condition or event influencing the dormancy state (Martin 1991). These phases are paradormancy, endodormancy and ecodormancy (Lang et al. 1987).

[1] Meristems are defined as regions where the cells maintain the ability to divide itself. Source: Taiz, L and Zeiger, E 2006 *Plant Physiology,* Sinauer Associates, Sunderland, Massachusetts.
[2] For a broad revision of tree dormancy other useful resource is Lakso, A 1994 'Apple', Schaffer, B & Andersen, P (eds.) in: *Handbook of environmental physiology of fruit crops. Volume I: Temperate crops*, CRC Press.

Paradormancy takes place in mid-summer until early autumn, the main mechanism affecting this stage is called apical dominance or correlative inhibition. Although the whole inhibition process is not fully understood, in most cases hormones such as auxin, cytokinin, gibberellin, ethylene and absisic acid regulate paradormancy (Jackson 2003, Horvath 2009, Campoy et al. 2011, Darbyshire 2013).

Endodormancy, also known as rest or true dormancy, is defined as a state where growth suspension is regulated by physiological factors originating within the bud itself (Ferree and Warrington 2003, Maguylo et al. 2012, Andreini et al. 2014). It starts around mid-autumn, being deeper in winter and cannot be broken by temperatures favourable for growth or adequate soil moisture (Voller 2004, Charrier et al. 2011, Darbyshire 2013). This state can only be released after exposure to a certain period of chilling temperatures called winter chilling or vernalisation (Charrier et al. 2011, Darbyshire et al. 2011, Maguylo et al. 2012).

After the buds overcome endodormancy, they move into the ecodormancy phase. In this stage the buds remain dormant due to unfavourable growing conditions, such as cold temperatures and water stress (Martin 1991, Dennis 2003, Horvath 2009). Ecodormancy lasts until early spring—generally September in Australia—when the buds have been exposed to suffice warm temperatures to reach green tip (Jackson 2003, Horvath 2009). Of these types of dormancy, endodormancy is recognised as true dormancy, hence hereinafter endodormancy is referred to as dormancy.

Dormancy induction, depth of dormancy and breaking appears to differ depending on the variety and the type of bud (Cook et al. 1998, Cook and Jacobs 1999, Maguylo et al. 2012). For instance, terminal buds in apples rapidly enter into dormancy in autumn, whereas the exit from dormancy begins slower but becomes faster, after the exposure of the buds to chilling temperatures, before green tip in spring (Cook et al. 1998, Jackson 2003, Maguylo et al. 2012). This is related to differences in chilling requirements at the bud level. Some authors noted that terminal buds of apple trees have a lower chilling requirement than the axillary buds (Paiva and Robitaille 1978, Saure 1985, Dennis 2003, Ramírez and Davenport 2013).

Salisbury and Ross (1992) state that the effects of chilling to break dormancy are on individual buds, rather than on the whole tree. Therefore, buds exposed to different temperatures within a tree may break dormancy at distinct times.

1.1.2 Green tip and Flowering

Flowering in pome fruit trees is part of a complex biological process of reproduction and development that starts in the previous summer with floral initiation and differentiation of the floral parts (Wilkie et al. 2008, Darbyshire 2013). The cycle continues in spring after the buds have fulfilled their chilling requirements and have received environmental signals promoting their growth (e.g. warm temperatures) (Wilkie et al. 2008, Horvath 2009, Darbyshire 2013). The first stage of flowering is called green tip. At this point, the buds show a green colour in their tips, and is also known as bud burst or budbreak (Darbyshire et al. 2012, Campoy et al. 2013). The timing of green tip depends primarily on temperature (Faust et al. 1997, Jackson 2003), with warmer temperatures associated with earlier dates when buds reach green tip stage (Heide 1993). However, factors such as species, variety and growing region may also have an influence on green tip timing (Strand et al. 1999).

Flowering timing, including green tip, differs between apple bud types (Strand et al. 1999). The precise nature of the relationships between environmental factors and the date of flowering is not yet clear (Campoy et al. 2012). A common method for determining blooming is relating the mean springtime temperature with the timing of the phase[3] (Grab and Craparo 2011, Darbyshire 2013). Winter temperatures have also been used as a predictor of the timing of green tip (Campoy et al. 2011).

1.2 Buds

Apple trees produce buds annually during the summer season. Buds are immature shoots systems, with or without flowers (Marini and Facts 2003, Jackson et al. 2011). These buds

[3] There are two other commonly used methods applied for accounting the spring progression, these are the growing degree days and growing degree hours see: Zavalloni, C, Andresen, JA and Flore, J 2006, Phenological Models of Flower Bud Stages and Fruit Growth of 'Montmorency' Sour Cherry Based on Growing Degree-day Accumulation, *Journal of the American Society for Horticultural Science,* vol. 131, no. 5, pp. 601-607, Darbyshire, R, Webb, L, Goodwin, I and Barlow, E 2012, Evaluation of recent trends in Australian pome fruit spring phenology, *International journal of biometeorology,* vol. 57, no. 3, pp. 409-421.

are the basis for flower and leaf formation for the next season and are thus a crucial part of the production cycle.

1.2.1 Bud types

The buds on apple trees can be located on long (extension) or short shoots (spurs) (Simpson 2010, Jackson et al. 2011). Long shoots are defined by Wilkie et al. (2008) as "[an] extension of the current season's growth…", whereas short shoots are those "in which the growth is limited to the production of a rosette with a few leaves".

Buds are important to the vegetative and reproductive growth of fruit trees. In apple trees buds can be vegetative and mixed (Simpson 2010). Only mixed buds contains flowers, usually from three to six, and can be found in all the types of buds in different proportions (Strand et al. 1999, Ferree and Warrington 2003, Ramírez and Davenport 2013).

Buds are classified as terminal, axillary or spur buds depending on their location. Terminal buds are located on the tip of long shoots, spur buds at the end of short shoots and axillary buds are located in the axils of the leaves (Schroeder 1921, Mitchell et al. 1994, Ferree and Warrington 2003, Jackson 2003, Simpson 2010).

These three types of buds, as outlined in Figure 1.3, were the subject of investigation in this research project.

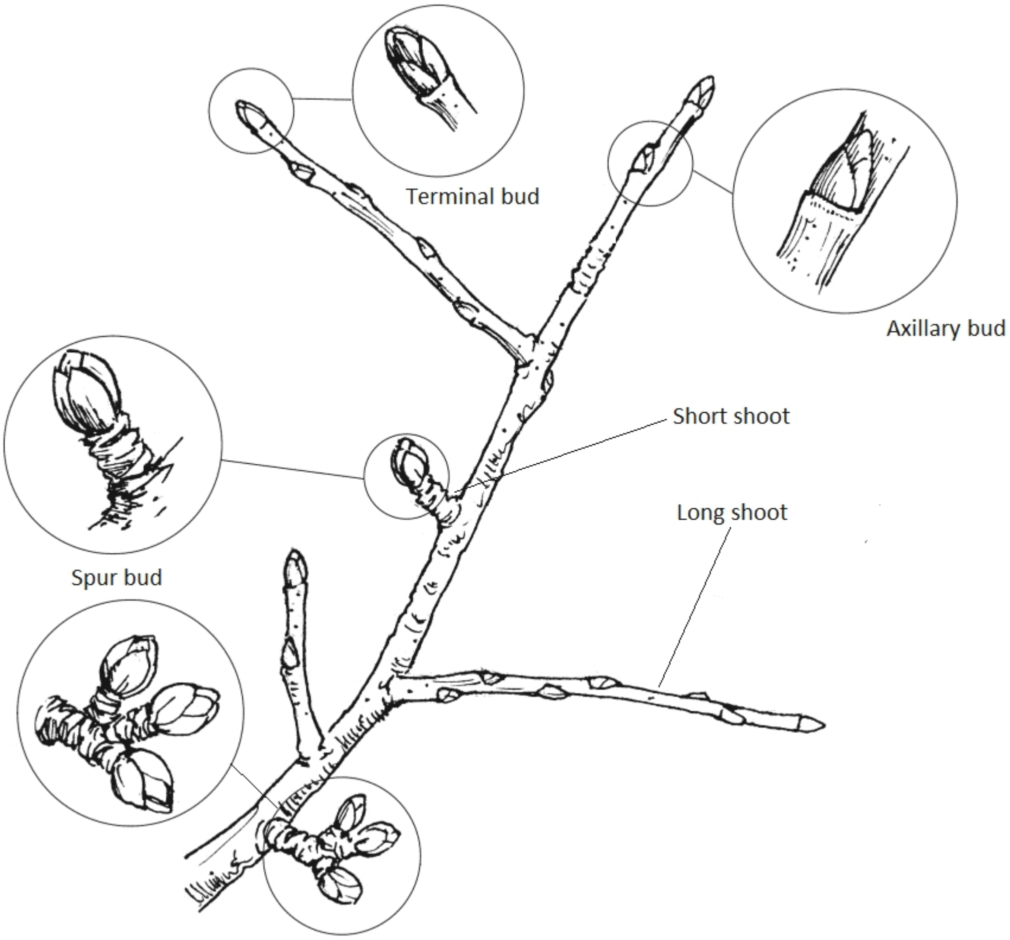


Figure 1.3: Schema of the different types of buds and shoots on an apple tree. Adapted from Phillips (2005).

1.2.2 Flower bud development

Flower development of all the bud types is influenced by local conditions (temperature, crop load, water stress) (Erez 2000, Ferree and Warrington 2003, Wilkie et al. 2008). The growth of axillary buds is also limited by the inhibition exerted by terminal buds, known as apical dominance (Rohde and Boerjan 2001, Jackson 2003, Costes et al. 2006).

1.3 Effects of temperature on the phenology of buds

In response to observed increases in temperature (IPCC 2013), direct temperature influences on the timing of the flowering phases of pome fruit trees have been investigated mainly at the whole tree, orchard or species scale (Estrella et al. 2007, Grab and Craparo 2011, Cook et al. 2012, Legave et al. 2013). The results of these studies show that temperature have an impact on both major phenological processes dormancy and flowering.

1.3.1 Effects of temperature on dormancy

According to Andreini et al. (2014) the consequences of inadequate chill due to insufficient exposure to chilling temperatures[4] are: 1) late bud break due to a late dormancy release; 2) low percentage of bud break; and 3) high percentage of flower bud drop. Others have outlined that inadequate chill can also lead to a prolonged flowering period, poor fruit development, small fruit size and uneven ripening times (Ferree and Warrington 2003, Darbyshire et al. 2011).

1.3.2 Effects on flowering timing

A high percentage of the studies investigating the effects of temperature on flowering timing have been implemented in the Northern Hemisphere, concluding that there has been an advance in flowering time (Chmielewski et al. 2004, Estrella et al. 2007, Legave et al. 2008, Legave et al. 2013). However, there are species that showed a delay in their flowering timing (Cook et al. 2012, Darbyshire et al. 2012). Cook et al. (2012) stated that the winter chilling period played a major role in the response of temperate wild species to temperature. They described two types of species those with spring-only response to temperature and those with divergent response. That is responses to both spring and autumn/winter temperatures. Species showing a delay in their flowering timing are categorised as divergent, since the interaction between temperatures across winter and spring influence their timing.

Only two studies have been carried out in the Southern Hemisphere assessing these effects on the phenology of pome fruit trees (Grab and Craparo 2011, Darbyshire et al. 2012), showing in general advancements in flowering timing but with different magnitudes. The only study of historical temporal trends in pome fruit phenology in Australia (Darbyshire et al. 2012) reported an advance in flowering phenophases for apple trees in three different

[4] To determine the exposure to chilling temperatures various models have been developed. For a review of the historical chill trends for deciduous fruit trees in Australia using some of these models see Darbyshire, R, Webb, L, Goodwin, I and Barlow, S 2011, Winter chilling trends for deciduous fruit trees in Australia, *Agricultural and Forest Meteorology,* vol. 151, no. 8, pp. 1074-1085.

locations. As can be noticed from Table 1.1, there are differences in the magnitude of change for varieties and sites. In the case of Granny Smith apples there are not only differences in the values but in the trends, showing an advance in the full bloom dates in Yarra Valley (1.4 days/decade) and a delay in Tatura (0.6 days/decade).

Table 1.1: Advance in days/decade of green tip and full bloom phenophases for apple trees in Australia, and trends for mean temperature in °C/decade for each location. Advances are reported as negative values and delays are positive values. Source: Darbyshire et al. (2012).

Variety	Phenophase	Advance (days/decade)	Location	Tmean trend (°C/decade)
Jonathan	Green tip	-2.5	Lenswood (SA)[a]	0.1
Granny Smith	Full bloom	0.6	Tatura (VIC)[b]	0.1
Granny Smith	Full bloom	-1.4	Yarra Valley (VIC)[c]	0
Golden Delicious	Full bloom	-1.9	Yarra Valley (VIC)[c]	0
Red Delicious	Full bloom	-3.5	Yarra Valley (VIC)[c]	0

Period [a] 1963-2009, [b] 1982-2009, [c] 1976-2005.

The effects of advances of flowering phenophase dates of pome fruit trees are diverse. Positive effects of advancements include early maturation that may be an advantage for growers as it could increase the market value of their fruit (Erez 2000). These advancements may also expose the young leaves and flowers to frost causing injuries in reproductive organs of the tree leading to yield losses (Rodrigo 2000). Additionally, Darbyshire (2013) suggested that changes in green tip and flowering times may lead to loss of synchronisation of flowering between cross-pollinating species, affecting the fruit set process.

A delay in green tip and flowering timing may also have adverse impacts. These include, poor leafing, reducing the leaf area and hence reducing photosynthesis and variability in the bloom period causing a reduction in fruit set and yield (Erez 2000). Furthermore, delays in green tip are linked with uneven and light budbreak exposing the leafless trees to direct insolation that may cause a progressive deterioration of the tree, due to the dryness of the exposed branches. With time this can affect yield and production (Erez 2000). Cook and Jacobs (1999) noted that the delay in green tip affects the buds differently. Delays in the green tip of axillary buds may reduce the number of developed branches.

Studies assessing the effect of temperature on green tip timing at bud level are scarce. One study has been conducted in South Africa aiming to assess the precedence of green tip (i.e. which bud type reached the green tip phase first) on terminal and axillary buds (Maguylo et al. 2012). Their results showed that the terminal buds of Golden Delicious broke first in almost all the cases. On the other hand, the terminal buds of the Granny Smith only broke first in 58% of the assessments in a cool area against 43% in a warm area. Despite which bud type broke first in Granny Smith, there was not a significative difference in the days, around 3 days, when terminal and axillary buds reached green tip in both areas. The opposite situation occurred in Golden Delicious where the delay between the green tip of terminal and axillary buds was more evident. The delay in the cool area was about 6 days, compared with the warm area where the delay was around 20 days. The authors hypothesised that these differences could be caused by variations in branch architecture between the two sites or the apical dominance exerted by terminal buds. On the other hand, differences in chilling accumulation between the two sites could be affecting the precedence of green tip in terminal and axillary buds.

1.4 Research Questions

Green tip timing, important for apples production, can be influenced by climatic conditions. In this context it is necessary to deepen the understanding of the response of individual apple buds to changes in climatic conditions in Australia. As such, this research proposed the following questions:

1. What is the variability in the timing of green tip between bud types in ‘Cripps Pink’ apple trees?
2. What are the differences in the timing of green tip across three locations and two years in Australia?
3. What is the relationship between temperature and the timing of green tip emergence by bud types ‘Cripps Pink’ apple trees?

2 Methods

2.1 Study Area

Three areas were selected to assess the effect of temperature on green tip timing, Applethorpe (QLD), Shepparton (VIC) and Manjimup (WA) (Figure 2.1). The selected study areas represent three of the main growing zones in Australia and each location has different climatic conditions (Table 2.1).

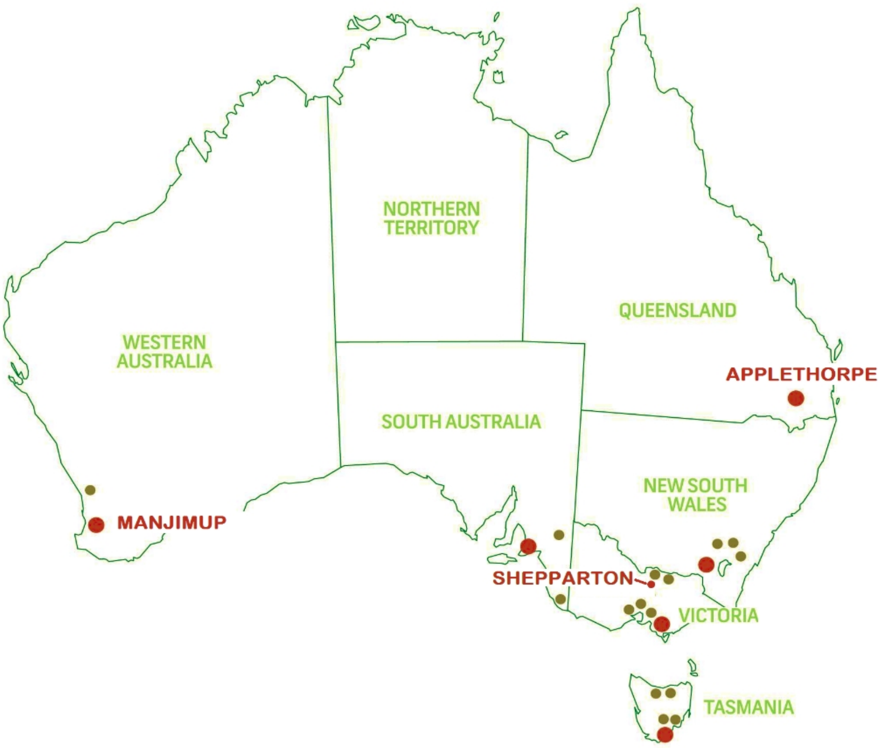


Figure 2.1: Apples production zones in Australia. The locations analysed in this study are highlighted in red. Adapted from APAL (2013).

Table 2.1: Summary of cultivar's locations, and historical winter and spring temperature (1911–2009). Source: Darbyshire (2013).

Site	State	Latitude	Longitude	Altitude (m)	Mean winter temperature range (°C)	Mean spring temperature range (°C)
Applethorpe	Queensland	-28.62	151.95	920.4	7.6–10.3	13.2–17.0
Shepparton	Victoria	-36.39	145.31	112	7.8–9.9	12.9–17.1
Manjimup	Western Australia	-34.18	116.07	286	9.6–12.4	12.0–15.3

2.2 Data

Day-of-year of green tip of terminal, axillary and spur buds for 2012 and 2013 springtime season were collected for individual buds. For this study terminal buds were considered as those located at the end of shoots > 2.5 cm, whereas spur buds those located on the tip of shoots ≤ 2.5 cm.

In total, 30 buds were monitored, 10 of each type which were randomly located throughout the canopy on all sides of the tree. This was repeated for five trees, thus a total of 150 buds were monitored per site (50 of each type). The progression of bud development was recorded three times per week from dormancy to full bloom in each location. Due to a lack of recorded data, axillary bud data for both years as well as terminal data for 2013 from Shepparton were excluded from the analyses.

Additionally, hourly temperature data were recorded at each site for 2012 and 2013.

2.3 Analytical approach

Temperature—Differences in temperature between locations and years were calculated using the arithmetic difference between mean temperatures for winter season.

Variability between trees—To test the presence of non-significant differences (H_0) in the median day-of-year of green tip between trees in each location a two tailed non-parametric analysis of variance test, Kruskal-Wallis (Kruskal and Wallis 1952, Zar 2010), was used over the data. To perform the analysis all the data from each bud type were grouped together by tree. The alternative hypothesis was that significant differences existed in the median day-of-year of green tip between trees. The significance level was set a p-value <0.05, if the given p-value is less than 0.05, non-significant differences can be rejected.

Normality of the green tip data—A normality test, Shapiro-Wilk test (Shapiro and Wilk 1965, Wilks 2011), was performed over the individual green tip data at each location for both years in order to decide the type of tests, parametric or non-parametric[5], that should be applied to the individual data. The null hypothesis (H_0) for this test was that the day-of-

[5] Non-parametric tests do not assume the normality of the data Dytham, C 2011 *Choosing and using statistics: a biologist's guide,* John Wiley & Sons.

year of individual green tip data was taken from a population with normal distribution. The alternative hypothesis (H_a) was that the samples came from a population with a non-normal distribution.

Variability between bud types—To test if there were non-significant differences (H_0) in the median day-of-year when individual buds reached green tip across Australia in both years a pairwise two-sample non-parametric test, Wilcoxon-Mann-Whitney (Wilks 2011) was used. To perform the test the significance level was set a p-value <0.05 (two sided).

All the statistical analyses were performed using R statistical software (R Core Team 2012).

3 Results

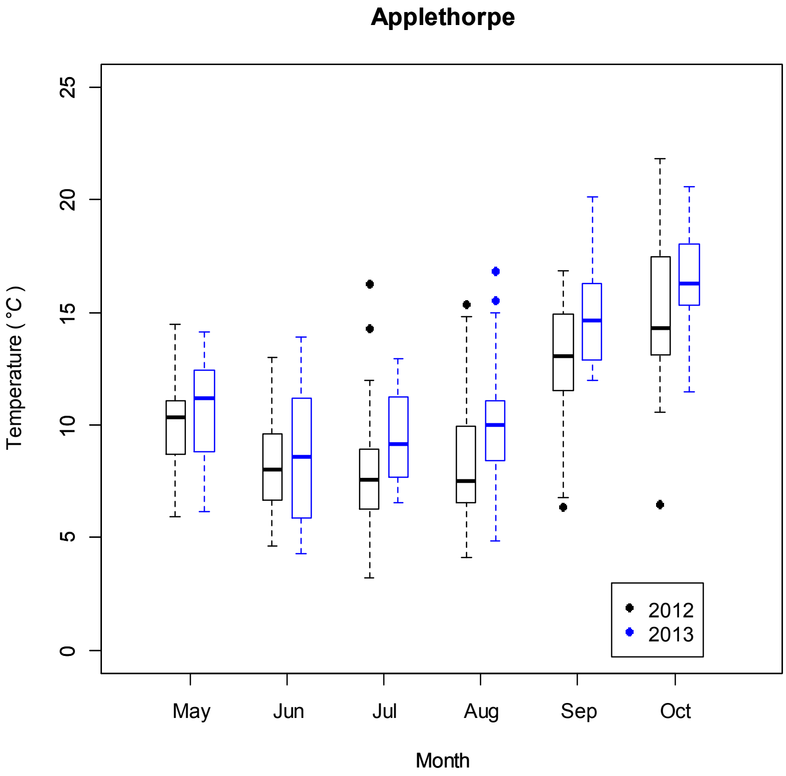
3.1 Temperature differences

Manjimup recorded the highest mean winter temperatures (June, July, and August) for both years about 3 °C higher than Applethorpe and Shepparton. Applethorpe recorded the highest spring temperatures in both years between 0.4–2.8 °C higher than Manjimup and Shepparton, respectively (Table 3.1).

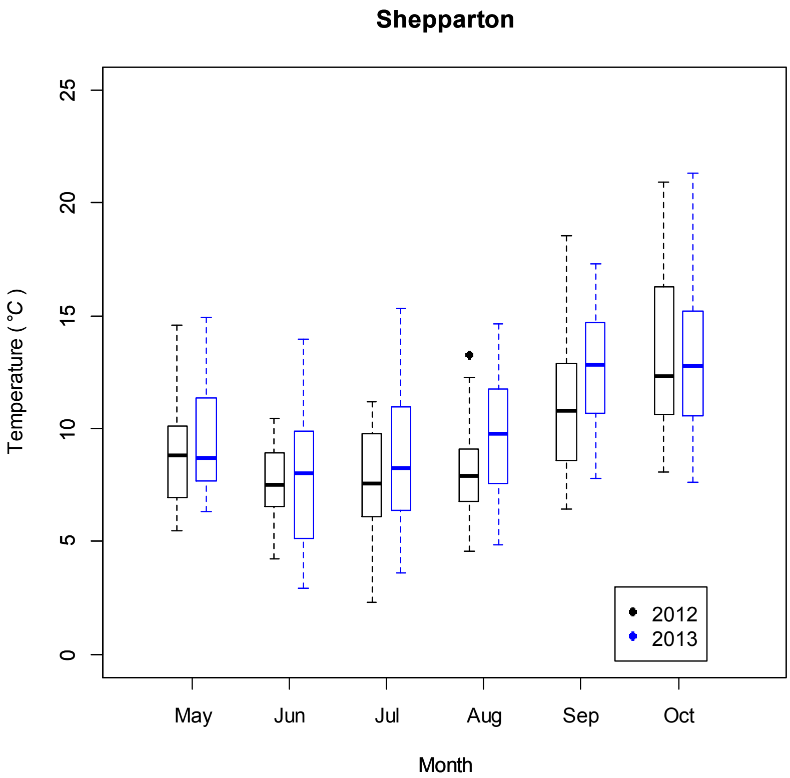
Table 3.1: Monthly mean temperature for the study for 2012 and 2013. The months highlighted in blue correspond to winter season. The months highlighted with green correspond to spring season. The notation used for the site is Applethorpe (App), Shepparton (She) and Manjimup (Man).

Site	Year	May	Jun	Jul	Aug	Sep	Oct
App	2012	10	8.3	7.9	8.5	12.6	15.1
	2013	10.7	8.7	9.4	10.0	14.9	16.6
She	2012	8.9	7.5	7.6	8.1	10.9	13.4
	2013	9.6	7.8	8.6	9.8	12.8	13.2
Man	2012	13.6	11.8	10.7	10.8	11.8	14.6
	2013	13.5	12.2	11.0	12.4	12.6	14.4

The winter and spring season temperatures for 2013 were higher than winter and spring temperatures for 2012 in all locations. Figure 3.1 presents schematic plots for the monthly winter and spring temperature for 2012 and 2013 in each location.


Applethorpe
Temperature (°C)
0
5
10
15
20
25
May
Jun
Jul
Aug
Sep
Oct
Month
2012
2013

a


Shepparton
Temperature (°C)
0
5
10
15
20
25
May
Jun
Jul
Aug
Sep
Oct
Month
2012
2013

b

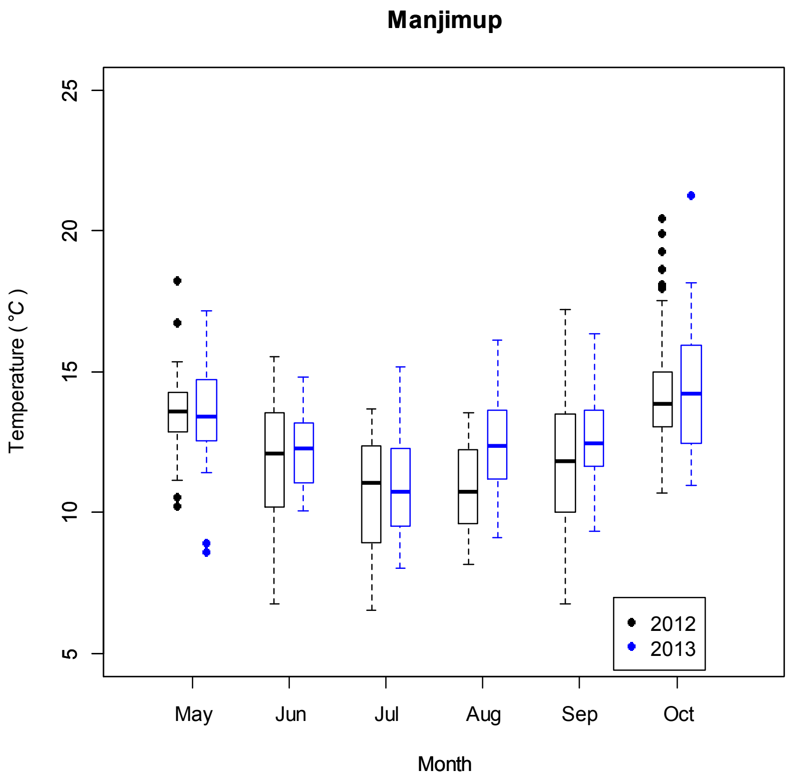


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Figure 3.1: Schematic plots of daily means winter and spring temperatures grouped by month for a) Applethorpe, b) Shepparton and c) Manjimup for 2012 (black) and 2013 (blue).

3.2 Variability between trees

The results of the non-parametric analysis of variance (Kruskal-Wallis) conducted on the green tip observations at the whole tree level (pooled data) indicate that there were not statistical differences between the trees, p-values ≥ 0.05 (Table 3.2). Therefore, the null hypothesis was accepted. These results demonstrate that differences in the day-of-year of green tip at each location were not driven by differences at the tree level, hence, statistical tests at the bud level were conducted.

Table 3.2: Results of Kruskal-Wallis test of the differences in the day-of-year in reach green tip between trees, p-values ≥ 0.5 means that there were no significant difference between trees.

		Kruskal-Wallis
Location	**Year**	**p-value**
App	2012	0.65
App	2013	0.14
She	2012	0.77
Man	2012	0.59
Man	2013	0.35

3.3 Normality of the green tip data

The p-values obtained in the Shapiro-Wilk test showed that the day-of-year when each bud type reached green tip follows a non-normal distribution in all locations for both years (p-value < 0.05), except axillary buds in Applethorpe and Manjimup for 2013 (Table 3.3). Therefore the alternative hypothesis was accepted, that is the green tip data come from a population with non-normal distribution, thus non-parametric tests were used to analyse the green tip data.

Table 3.3: Shapiro-Wilk test for each data set. The highlighted cells represents data with normal distribution (p-value ≥ 0.05).

Variety	Location	Bud type	Year	n	Shapiro-Wilk p-value
Cripps Pink	App	Axillary	2012	49	<0.05
	App	Axillary	2013	38	0.19
	App	Spur	2012	50	<0.05
	App	Spur	2013	50	<0.05
	App	Terminal	2012	50	<0.05
	App	Terminal	2013	50	<0.05
	She	Spur	2012	32	<0.05
	She	Spur	2013	50	<0.05
	She	Terminal	2013	50	<0.05
	Man	Axillary	2012	28	<0.05
	Man	Axillary	2013	23	0.07
	Man	Spur	2012	36	<0.05
	Man	Spur	2013	40	<0.05
	Man	Terminal	2012	34	<0.05
	Man	Terminal	2013	40	<0.05

3.4 Day-of-year of green tip

The day-of-year when the measured buds reached green tip differed according to location and bud type (Table 3.4). Buds in Shepparton burst first in 2012 marking the beginning of the green tip phase, 241 day-of-year, followed by Applethorpe, 243 day-of-year, and almost 20 days later those located in Manjimup burst, 262 day-of-year for 2012. In 2013 buds in Shepparton and Applethorpe burst on the same day-of-year, 244 day-of-year, followed by Manjimup, 260 day-of-year. A similar trend was found for the median day-of-year of green tip in both years. These results show that generally spur buds were the first buds to reach the green tip phase, whereas axillary buds where the last to reach this phase at all locations and for both years (Table 3.4).

All bud types burst later in 2013 than in 2012 at all locations, excepting spur buds in Shepparton, which showed an advancement of 1 day compared with 2012 in the median day-of-year when buds reached green tip (Table 3.4). The range of this delay in 2013 compared with 2012 was from 1 (spur buds in Applethorpe and terminal buds in Manjimup) to 13 days (spur buds in Manjimup).

3.5 Length of green tip stage

The length of the green tip stage was calculated by subtracting the day-of-year when the first bud reached green tip from the day-of-year when the last bud in burst. The length of this stage across Australia varied widely between locations, bud types and the two years. The length varied between 5 days for terminal buds in Shepparton for 2013 to 40 days for spur buds in Manjimup in 2013 (Figure 3.2). The buds from trees in Manjimup recorded the highest average length of green tip stage in both years, approximately 28 days, followed by Applethorpe, 22 days, and finally Shepparton, 11 days[6]. The length of the green tip stage was longer in 2013 at all locations and for all bud types, except for spur buds in Shepparton which burst over a period of 7 days in 2013 compared with 21 days in 2012. The difference in the length of the green tip phase between years was largest at Manjimup with an average increase of 13 days with terminal buds demonstrating the largest lengthening of 15 days. Differences in length were also present between bud types within locations, axillary buds in Applethorpe burst over a longer time in both years (25 and 35 days in 2012 and 2013 respectively), whereas spur buds in Manjimup recorded the highest spread (28 and 40 days for 2012 and 2013 respectively). The median absolute deviation (MAD) presented in Table 3.4, shows the same trend where longer lengths are positively correlated with higher MAD values.

[6] Datasets of spur and terminal buds only.

Table 3.4: Summary of median day-of-year of green tip and length of the phase for each type of bud and location for Cripps pink apple. Blue and orange cells are the maximum and minimum values for each parameter respectively. **Where:** n: number of buds, DOY: Day-of-year, MAD: Median absolute deviation, FDOY: First day-of-year, LDOY: Last day-of-year, LGT: Length of green tip phase and IQR: Interquartile range.

Site	Bud type	Year	n	Median (DOY)	MAD (days)	FDOY	LDOY	LGT (days)	IQR (days)
App	Axillary	2012	49	264	6	246	271	25	13
App	Axillary	2013	38	267	7	251	286	35	10
App	Spur	2012	50	246	3	243	262	19	4
App	Spur	2013	50	248	4	244	265	21	7
App	Terminal	2012	50	247	1	243	255	12	2
App	Terminal	2013	50	253	7	244	262	18	8
She	Spur	2012	32	247	4	241	262	21	7
She	Spur	2013	50	246	3	244	251	7	2
She	Terminal	2013	50	248	0	246	251	5	3
Man	Axillary	2012	28	281	7	275	290	15	10
Man	Axillary	2013	23	286	10	273	300	27	10
Man	Spur	2012	36	269	5	262	290	28	6
Man	Spur	2013	40	282	9	260	300	40	12
Man	Terminal	2012	34	281	5	275	295	20	5
Man	Terminal	2013	40	282	4	265	300	35	3

The length of the green tip phase where half of the observations were concentrated (IQR) was significantly shorter than the total length of the green tip phase (LGT), but showed similar trends. IQR is shown graphically in Figure 3.2 as the observations inside the boxes, additionally the full distribution of the day-of-year when each type of bud reached green tip in 2012 and 2013 is displayed in the same figure.

For instance, spur buds in Manjimup for 2013 burst over 40 days; however the IQR was only 12 days, that is it took an extra 28 days to complete the green tip phase. Likewise, the results showed a mix of right, none (almost evenly distributed) and left green tip data skewed, representing where most of the green tip was concentrated. All the axillary buds had none or left skewness meaning that the development of the phase was slower at the beginning and then the remaining buds burst quickly. Conversely, terminal and spur buds had none or right skewness in the observations. In this case, the most of the buds burst at the beginning of the stage and only a few buds burst slowly towards the end of the phase. In addition, although the LGT varied widely between buds, locations and years, between 5–40 days, the IQR had a less variability, between 2–13 days, which means that 50% of the observations occurred in this narrower period of time. For instance, the terminal buds of 'Cripps Pink' apple grown in Manjimup for 2013 burst over 35 days; however, 50% of the buds burst in only 3 days, that is it took 32 extra days to complete the green tip phase.

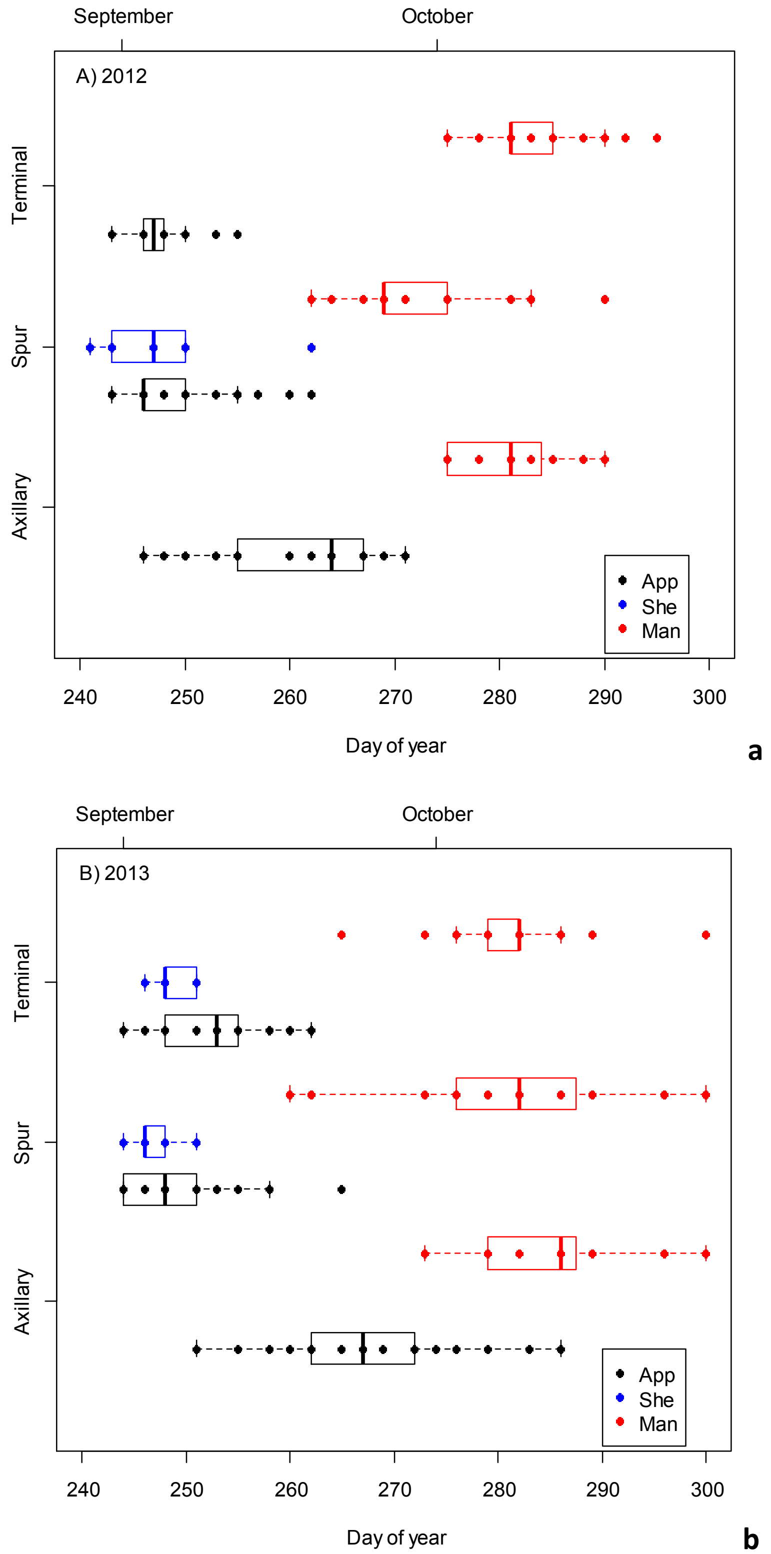

Figure 3.2: Observed green tip day-of-year for Cripps pink apple buds in Applethorpe (QLD, black circles), Shepparton (VIC, blue circles) and Manjimup (WA, red circles) for a) 2012 and b) 2013.

3.6 Variability in green tip timing

The results of the pairwise Wilcoxon-Mann-Whitney test shows a relative high number of significant differences between bud types both within and between sites (p-values < 0.05). Table 3.5 presents the results of the pairwise test, where the values in each cell represent the probabilities of similarity or non-similarity in the day-of-year of green tip between bud types (all the columns, rows and cells with non-significant similarity have been removed).

Table 3.5: Pairwise Wilcoxon-Mann-Whitney results for individual buds of Cripps Pink apple. Values highlighted represent samples with statistical equal medians (p-values > 0.05). Na are non-meaningful comparisons.

			App Spur 2013	App Terminal 2012	She Spur 2012	She Spur 2013	Man Axillary 2013	Man Spur 2013	Man Terminal 2012	Man Terminal 2013
App	Spur	2012	0.10	0.44	0.97	Na	Na	Na	Na	Na
App	Spur	2013		-	-	<0.05	Na	<0.05	Na	Na
She	Spur	2012	-	-		0.46	Na	Na	Na	Na
Man	Axillary	2012	-	-	-	-	0.08	Na	0.37	Na
Man	Axillary	2013	-	-	-	-		0.30	Na	<0.05
Man	Spur	2013	-	-	-	-	-		Na	0.38
Man	Terminal	2012	-	-	-	-	-	-		0.67

Only Applethorpe and Manjimup presented significant intra-site similarities in the median day-of-year when buds reached green tip. For Manjimup, axillary and terminal buds showed a similarity in the day-of-year of green tip in 2012 (p-value = 0.37). Whilst, for 2013 axillary, terminal and spur buds burst in a similar day-of-year.

For Applethorpe the spur and terminal buds reached green tip in a similar day-of-year in 2012 (p-value = 0.44), whereas only spur buds burst in a similar day-of-year in 2012 and 2013 (p-value = 0.10). There were no similarities between bud types for 2013.

The p-values of the non-parametric test for equal medians show that none of the sites had statistical similarity in the day-of-year of green tip at Manjimup. Furthermore, only the spur buds in Applethorpe and Shepparton burst in a similar date in 2012 (p-value = 0.97). There was no similarities for 2013 across sites.

4 Discussion

4.1 Differences in green tip timing

The results showed that spur buds were the first buds to reach green tip in all locations for both years, followed closely by terminal buds and later axillary buds. The results confirmed that these differences were not driven by differences between trees (Table 3.2), but by the bud types (Table 3.5). These differences agree with previous results from Paiva and Robitaille (1978) and Naor et al. (2003). Both studies found that terminal buds burst earlier than axillary buds. Maguylo et al. (2012) found a similar response for terminal buds of Golden Delicious and Granny Smith apple which burst early than axillary buds. However, the authors did not find any significant difference in the day-of-year of green tip between terminal and axillary buds of Granny Smith, which is only comparable with the green tip data for 2013 in Manjimup. Factors affecting these differences may be related to the variety, the area and local climate conditions. It is not clear if any of these authors made a distinction between terminal and spur buds.

Naor et al. (2003) state two main underlying reasons influencing the differences in green tip timing between terminal/spur and axillary buds. Firstly, the specific chilling requirements of each type of bud and secondly, the apical dominance exerted by terminal and spur buds over axillary buds. A combination of these two phenomena may be influencing the delay of green tip in axillary buds. This delay was observed at Applethorpe, in both years, where the median day-of-year when axillary buds reached green tip was after the end of the green tip phase for the spur and terminal buds. However, as was discussed above, this behaviour was not observed at Manjimup. The non-parametric test of significance showed that the differences in the day-of-year of green tip between axillary and spur buds were not significant in the 2013 season at Manjimup.

It is possible that bud positioning may be driving some of the observed variability in timing between the bud types. Cook and Jacobs (1999) found that the relative position of the bud in the shoot may have an influence in the timing of green tip. Buds closer to the end of the branches (distal buds) reached green tip phase first, whereas buds closer to where the branches are attached to the trunk of the tree (proximal buds) were inhibited and burst later.

Tree architecture and training systems at each location may have influenced the day-of-year of green tip (Campoy et al. 2011). For instance, Erez (2000) and Naor et al. (2003) argue that the orientation of the branches has an effect on green tip timing due to changes in hormone balances in the buds. They found that buds located on horizontally oriented branches burst earlier than those located on upright ones.

4.2 Effect of temperature on green tip timing

In general, the differences in green tip timing across locations were statistically significant. These differences could be related to the differences in winter temperature between the locations. The coldest region in winter was Shepparton followed by Applethorpe and Manjimup, about 8.2, 8.8 and 11.5 °C in average for both years respectively. This was consistent with the order in which the buds burst across sites. That is, green tip occurred earlier in Shepparton and Applethorpe than in Manjimup.

Other studies have also found differences in green tip timing between locations. Maguylo et al. (2012) found significant differences between areas with different temperatures in the day-of-year of green tip of terminal and axillary buds for Golden Delicious apple. The delay of axillary buds compared with the terminal buds was larger in the warmer area (20 days) than the cooler area (6 days). The results of this research show an opposite relationship, the biggest delay in green tip between these two types of buds was found in one of the coolest areas, Applethorpe around 15 days, than the warmer area, Manjimup approximately 3 days. Although the differences may be related to the varieties and their specific chilling requirements, further research is needed using data from the same variety and information about chilling requirements.

Similarly, the length of the green tip phase was consistent with differences in winter temperature. On average across all bud types in Manjimup green tip occurred over a period of approximately 28 days, followed by Applethorpe and Shepparton[7], approximately 22 and 11 days, respectively. However, there was not a clear trend in the length of the green tip phase within sites. For instance, the buds which burst over the longest period of time were axillary buds in Applethorpe and spur buds in Manjimup (for both years). On the other hand,

[7] Only information about terminal and spur buds.

the buds that burst quickest were terminal buds in Applethorpe and axillary buds in Manjimup. Further research is needed to understand the cause of these differences.

Comparison between winter temperatures for both years showed that the 2013 winter season in all locations was warmer than the winter temperature for 2012, about 1 °C higher in all locations. Coupled with these higher winter temperatures a delay in the day-of-year when the buds reached the green tip phase was observed in all locations. Spur buds in Shepparton were an exception which showed an advancement of 1 day.

It was observed that the LGT and MAD were greater for 2013 (except for spur buds in Shepparton), whereas the IQR of the observations were only greater in spur and terminal buds in Applethorpe and spur buds in Manjimup for 2013. These results suggest that the LGT and MAD (length and variability of the green tip phase) were more responsive to the increases in mean winter temperature than the IQR, i.e. the length of time where green tip was more intense was not directly affected by winter temperatures. One possible explanation is that buds had suboptimal chilling due to warmer temperatures during dormancy in 2013 (Cannell and Smith 1986). Therefore, each type of bud may have broken the dormancy at different dates, causing a delay and a sporadic green tip in some cases (buds with longer LGT). Results from Tromp (1976) shows a similar tendency when apple trees were exposed to different temperatures during the dormancy phase, those exposed to warmer temperatures demonstrated a delayed green tip. Similar trends were found by Cook and Jacobs (1999) where buds growing in warmer areas burst more erratically and unevenly than buds exposed to colder temperatures.

Although a number of studies have found that advances in flowering are linked with increases in temperature (Chmielewski et al. 2004, Estrella et al. 2007), the result from this study suggest that warmer temperatures in winter have the opposite effect on green tip timing, i.e. causing a delay. This effect has been discussed by Cannell and Smith (1986) and more recently by Cook et al. (2012) and Pope et al. (2013). Not all the species respond the same way to changes in temperature and the results of this investigation suggest that 'Cripps Pink' apple, for the locations investigated, can be either responsive only to winter temperatures or both spring and winter temperatures. Moreover, Darbyshire et al. (2012) found delays in the historical trend of flowering of two one variety of apple (Granny Smith) and one of pear (William's Bon Chretien) which showed a delay in the full bloom timing of

0.6 and 1.4 days/decade respectively. Analyses of flowering and its responses to winter and spring temperature may help to understand the effects of temperature in the spring phenology of this variety. Due to data restrictions these analyses were not carried out in this study, as a model could not be constructed.

4.3 Sample size

Temperature data was used to infer differences in green tip timing for different bud types. Additional data is needed to allow a greater analysis of the drivers of green tip timing of different bud types. Information about bud position (relative to the top of the tree, the shoot and the branch) may help to explain differences in timing and variability between bud types across locations. In addition, information about completion of the dormancy stage (chilling requirements) and specific heat requirements of the different bud types may give an idea about the beginning, variability and spread of the green tip phase.

Similarly, despite that the use of the recorded winter temperatures helped to provide an explanation about the differences in the date and variability of green tip between bud types, location and years, it did not give enough information to explain differences in progression of the stage, specifically in differences in LGT and burst intensity. Improving the sample size would provide better explanations of these phenomena. Furthermore, since apple trees can have about 200–600 buds, depending on the tree size and training system, the sample size (30 buds per tree) represents around 2.5–15% of the total number of buds. Authors such as Luedeling (2012) argue the need for improved representativeness of the samples to improve the accuracy of the results and reduce uncertainty. Depending on available resources, factors such as the percentage of each type of bud in the tree could be used to establish a weighted sample depending on the type of bud. Moreover, the variability reported in this study (MAD) can be used to calculate the ideal sample size given an initial estimation error (usually less than 10 %).

4.4 Climate change implications

The projections of the ensemble of global climate models presented by IPCC (2013) reported that temperature increases will continue in the future. For instance, it was projected that mean winter temperature for 2035 will increase by 0.5–1 °C across most Australia compared with 1986–2005 baseline, results similar to those constructed by CSIRO

(2007). However for 2065 and 2100 it is expected that zones around Applethorpe will suffer an increase of 1.5–2 °C and 2–3 °C respectively, compared with Manjimup and Shepparton 1–1.5 and 1–2 °C respectively (IPCC 2013). Given these possible scenarios, further shifts in flowering dates are likely.

Following the discussion of Darbyshire et al. (2013) future increases in temperature will reduce the amount of chilling over Australia. This may cause shifts and/or a reduction of the suitable area for growing other pome fruit varieties and species (Webb and Whetton 2010). Moreover, the author note that the impacts of increases in mean winter temperature will be different depending on the location. Thus, sites currently colder, may demonstrate a lower impacts than sites currently warmer. Therefore, according to the results of this research the delay in spring phenology for trees located in Manjimup might be bigger in the future, as well as the difference in days in reaching green tip with Shepparton and Applethorpe.

The impacts of increases in temperature can vary, from delays in green tip and flowering timing (Cannell and Smith 1986) to reduction in yield (Erez 2000) and loss of suitable area for growing crops (Webb and Whetton 2010). Therefore, adaptive strategies are needed to mediate these expected impacts of climate change. In this context, Webb and Whetton (2010) describe some options for Australian agriculture sectors. Some of these strategies include assessments of the current growing areas to select sites suitable to maintain production and development of new varieties with lower chill requirements that will be suited to new climatic conditions.

5 Conclusion

The day-of-year when buds reached the green tip phase varied significantly—with a few exceptions—with bud type, location and year. In general, the first buds to burst were spur buds, followed by terminal and axillary buds. There was a consistent relationship between temperature and date of green tip across locations. Areas with higher winter temperatures had later day-of-year of green tip than areas with lower winter temperatures. This delay in green tip timing was found experienced for almost all types of buds in all locations. However, there was not a clear relationship between temperature and the period of time when green tip was more intense (IQR).

Winter temperature provided insights into explaining the differences in green tip timing between bud types, locations and years. Nevertheless, a bigger sample size and additional data is needed in order to understand the observed differences. These data include information about relative position of the buds, orientation of the trees, tree architecture, management of the orchards, training systems, temperature of the buds and chilling and heat requirements. Similarly, it is important to investigate how the variability in green tip timing reported in this study affects subsequent developmental phases and overall productivity. Additionally, it is important to develop comparative studies with other apple varieties and other pome fruit species, such as pears, to improve knowledge at the bud scale and to develop better adaptive measures for possible future climate impacts.

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